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**CONTRIBUTIONS TO OCEANOGRAPHY AND FISHERIES
BIOLOGY**
BYDRAES TOT OSEANOGRAFIE EN VISSERYBIOLOGIE



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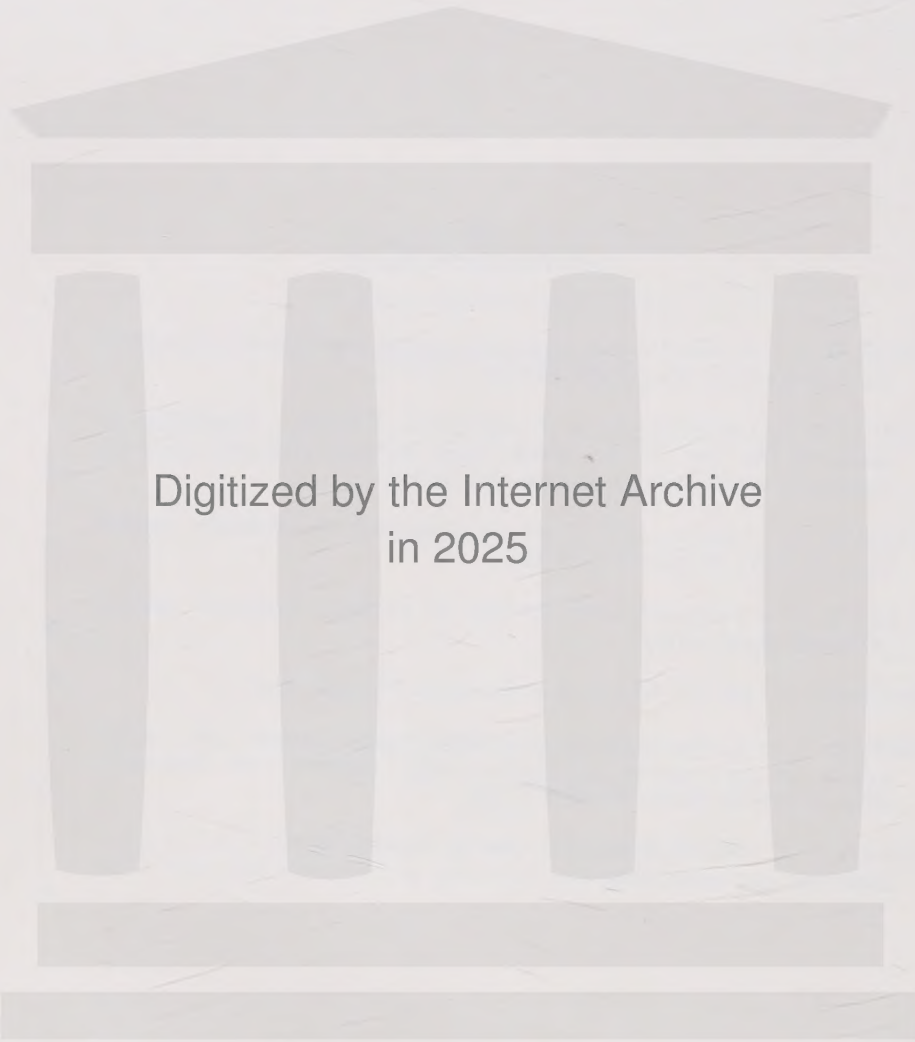
A. I. L. Payne

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A RÔLE FOR THE *NIMBUS-G* COASTAL-ZONE COLOUR SCANNER IN THE MANAGEMENT OF A PELAGIC FISHERY

D. L. CRAM

Research has shown that pilchard shoals off the South West African coast tend to avoid areas of dense phytoplankton or zooplankton and that they are more common where intermediate densities occur. Results from *Landsat-1* images indicate that the use of the far more applicable Coastal-Zone Colour Scanner of *Nimbus-G* to detect plankton, particularly high or low values of certain types, will yield information on the probable absence of pilchard in certain areas. This information could be used to minimize the search component of fishing effort and to refine assessments of pilchard stock by means of catch-per-unit-effort calculations.

Navorsing aan die Suidwes-Afrikaanse kus het aangetoon dat sardynskole neig om gebiede met hoë fito- en soöplankton te vermy en meer algemeen in 'n omgewing van intermediêre planktondigtheid aangetref word. Na aanleiding van resultate wat reeds met *Landsat-1* behaal is, word verwag dat die meer gespesialiseerde kleursensor (CZCS) aan boord van *Nimbus-G*, in die geval van sekere tipes plankton, sal kan onderskei tussen gebiede met lae en hoë konsentrasies. Sodoende sal informasie verkry word oor die waarskynlike verspreidingsgebied van sardynskole, wat kan lei tot 'n ekonomieser ontplooiing van die vissersvloot en terselfdertyd die akkuraatheid van vissstapelberamings deur middel van berekenings van vangs per pogingseenheid sal verhoog.

Between 1970 and 1974, the South-East Atlantic pilchard *Sardinops ocellata* (Pappe) was extensively studied by means of multidisciplinary surveys. After a relaxation of survey effort between 1974 and 1976, a new survey programme, which should ultimately include observations with the Coastal-Zone Colour Scanner (CZCS) of the proposed *Nimbus-G* satellite, has been planned.

The long series of observations on the pilchard population from both aircraft and ship makes the species an ideal subject for an evaluation of the rôle of satellites in pelagic fish management. In many coastal fisheries conducted from relatively few ports, the distribution of fish has considerable impact upon scientific and economic matters. In the South-East Atlantic, the whereabouts of pilchard shoal groups may be partly governed by phytoplankton distribution, and it may be possible to use the CZCS to identify distributions of phytoplankton communities while synchronously making surveys to locate the shoal groups and to collect other ground-truth data. Taken together, the two sets of data may show whether ocean colour and temperature, both of which are recorded by the scanner, influence the distribution of pilchard. The results of such an analysis may indicate that a reduction in expensive ship and aircraft survey time could be made in favour of a greater contribution from satellite studies.

BRIEF DESCRIPTION OF THE COASTAL-ZONE COLOUR SCANNER

Objectives

The primary objective of the CZCS is the detection and measurement of chlorophyll concentrations in the oceans of the world. Other important applications include studies of pollution, such as river silting and industrial effluent discharge. Because of the design characteristics of the sensor, it is possible that certain marine resources such as krill may be directly detected by the CZCS, despite its coarse spatial resolution.

Characteristics of the CZCS

The CZCS will have six spectral channels. Five of these measure the visible and near infrared solar radiation back-scattered from the depths of the ocean, and one, the thermal radiation emitted from the sea surface (Table I).

The *Nimbus-G* satellite will be in a sun-synchronous orbit designed to cross the equator at local noon and pass directly above a point on the earth's surface in South African latitudes once every six days (depending upon launching accuracy). The altitude of the satellite will be

Table I: *Nimbus-G* CZCS sensor characteristics

Channel	Bandwidth (micrometers)	Purpose
1	0,433–0,453	Chlorophyll absorption
2	0,510–0,530	Chlorophyll correlation
3	0,540–0,560	Gelbstoffe (yellow substance)
4	0,660–0,680	Chlorophyll absorption
5	0,700–0,800	Surface vegetation and land-water margin (Band 6 of <i>Landsat-1</i> multispectral scanner)
6	10,5–12,5	Surface temperature

955 km and the sensor swath width will be 1 566 km which, in South African latitudes, will permit observation of the same point on at least two passes of the satellite. All channels of the CZCS will have the same field of view and a resolution of 825 x 825 m.

RELEVANT SURVEY RESULTS

Aerial and acoustic surveys

Aerial observations by eye and with low-light-level television show that pilchard shoals vary considerably in size, occasionally 1 000 – 5 000 m long but usually smaller (Cram and Agenbag 1974). Pilchard shoals tend to congregate into large shoal groups frequently consisting of many thousands of shoals. This patchiness, plus the mobility of the shoal groups, led to the development of an aerial-acoustic survey strategy for the estimation of stock size (Cram and Hampton 1976). On certain occasions, an aerial survey or a combined aerial and acoustic survey was run concurrently with a hydrobiological survey, and when plankton distributions were compared with fish distributions, it appeared that the shoal groups tended to avoid dense plankton.

Hydrobiological surveys

According to Boney (1975), areas very rich in phytoplankton are avoided by zooplankton and fish. Field observations in the North Sea show that dense concentrations of species of the diatom genera *Phaeocystis*, *Coscinodiscus* and *Rhizosolenia* are avoided by fish. Vast (up to 160 km in extent), dense patches of *Phaeocystis pouchettii* are alleged to have deflected herring migration

routes, causing a shift in spawning grounds and a perturbation in the fishery.

The exclusion of pelagic fish by high concentrations of phytoplankton and zooplankton was observed during the course of surveys (from September 1970) of the pelagic fish populations and their immediate environment off South West Africa. Phytoplankton studies by Kruger (1972) demonstrated that the richest phytoplankton concentrations (mainly *Fragilaria karstenii* and *Chaetoceros* spp.) occurred as a so-called belt (although patchy) parallel to the coast in the water of lower oxygen content. King (1972) stated that the main zooplankton belt (principally copepods) stretched from the phytoplankton belt seawards increasing in concentration with distance from the shore. Visser *et al.* (1973) demonstrated the existence of different zones of phytoplankton and zooplankton abundance, corresponding to increasing average temperature (0–50 m) in a seaward direction (Table II).

Table II shows that there was a phytoplankton zone inshore followed by an intermediate zone of differing phytoplankton and zooplankton concentrations and a zooplankton zone off shore. The average temperature of the intermediate zone was 13,68 – 14,76°C. De Vos and Visser (1972) stated that most of the commercial pelagic fish catches were made, and most fish spotted, in water with a temperature of 14 – 15°C, coinciding with that of the intermediate zone.

A comparison of fish spotting observations, catch positions and depth distributions of pelagic fish with hydrographical, phytoplankton and zooplankton information showed that the main concentrations of pelagic fish were found in the so-called intermediate zone (Fig. 1). This conclusion suggests that pelagic fish avoid the rich phytoplankton and zooplankton areas but feed in areas of intermediate concentrations of both.

Table II: Changes in proportions of phytoplankton and zooplankton with increasing mean temperature (0–50m) seawards

Zone	Mean temperature (°C)
phytoplankton	13,22
2/3 phytoplankton and 1/3 zooplankton	13,68
1/2 phytoplankton and 1/2 zooplankton	14,36
1/3 phytoplankton and 2/3 zooplankton	14,76
zooplankton	14,64

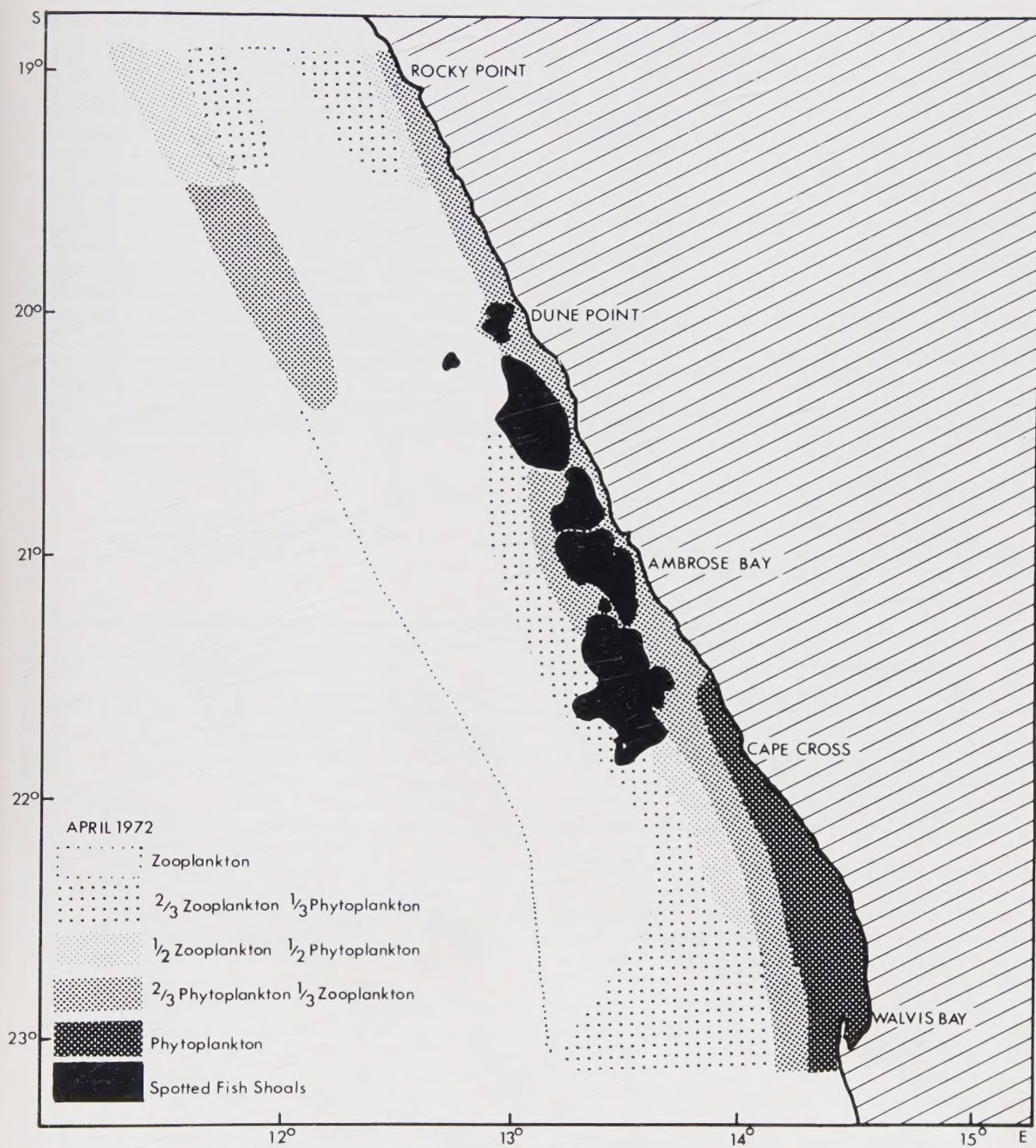


Fig. 1: Plankton distribution and observed positions of pilchard shoal groups – cumulative over 10 days (after Visser *et al.* 1973)

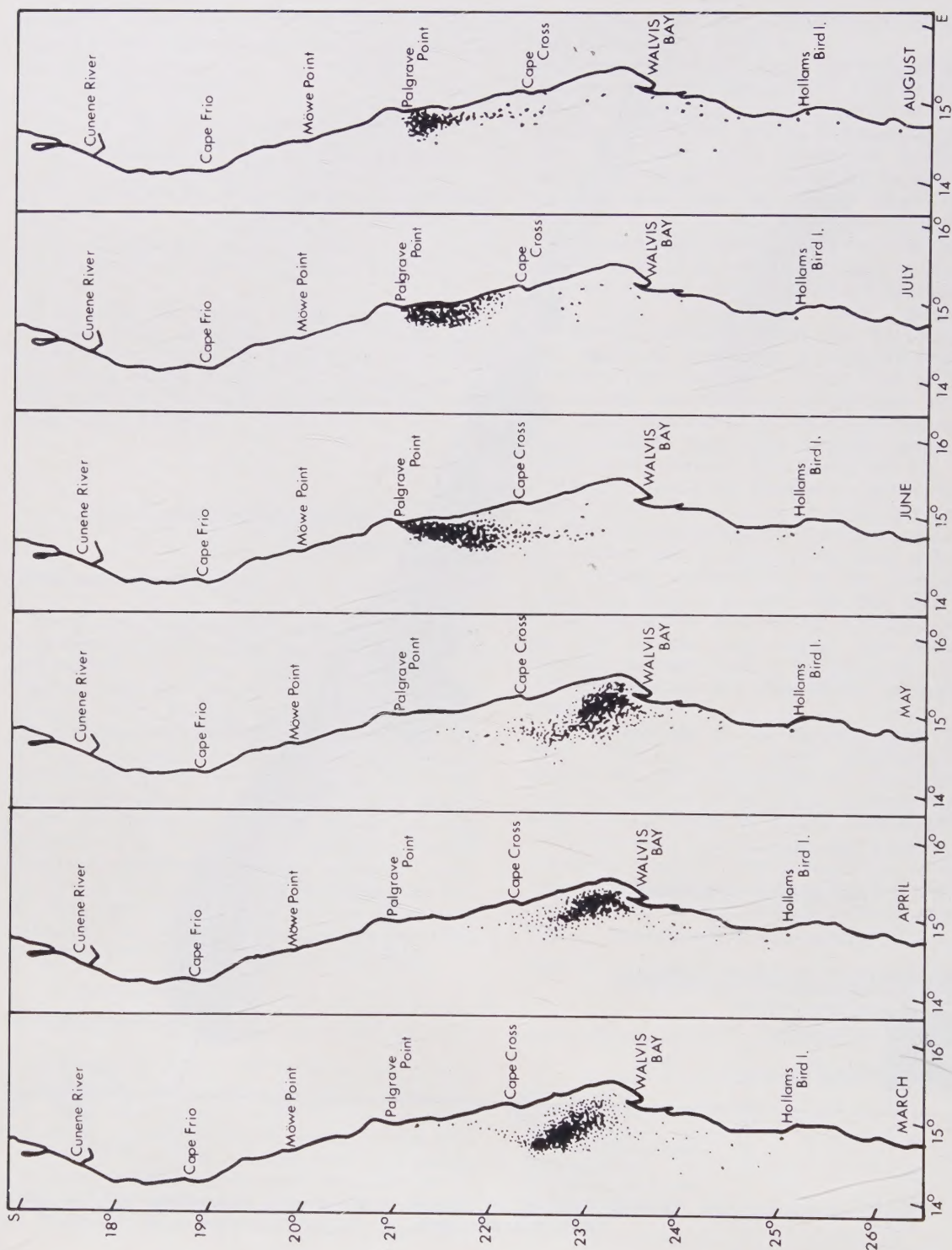


Fig. 2: Pilchard catch positions in 1973 (after Schülein 1974)

Fishery statistics

The main pelagic fishing grounds of South West Africa lie north of Walvis Bay where all but one of the processing factories are located. The fishing fleet always endeavours to catch fish as near the shore factories as possible and, owing to information exchange by radio, this means, in practice, on the southern end of the nearest shoal group. As shoal groups shift north, or become fished out, the catch positions move north. During the early seventies, the trend was for a northward shift of catch positions as the fishing season progressed (Schülein 1974). Figure 2 reflects this trend. Unfortunately, the positions of shoal groups were not always mapped during the fishing seasons, but an example, from April 1972, demonstrates the concentration of commercial effort on the southern end of a shoal group (Fig. 3).

BASIC CONCEPT OF AN INVESTIGATION

Because pilchard shoal groups tend to occupy an intermediate zone between the high concentrations of phytoplankton and zooplankton, and because the shoal groups apparently actively avoid dense phytoplankton, it is conceivable that such ecological factors could affect the availability of pilchard to the industry. Survey data show that the distribution of phytoplankton populations in the inshore zone dominated by *Fragilaria karstenii* can change quite rapidly, and also that this zone can occasionally cover the whole of the southern half of the fishing grounds. Under these conditions the fish would be displaced to the north. Conversely, if ecological conditions allowed them to approach Walvis Bay more closely, the fish would become more available to the fleet.

This ecological control of availability affects one of the important indices of abundance, the catch per unit effort (CPUE). In a situation, such as is found off South West Africa, where the CPUE index of abundance used is relatively unsophisticated and expressed as tons of fish landed per litre of fuel used, the distance steamed while searching can be biased by movements of the shoal groups. Thus, CPUE indices such as catch per search area or catch per quantity of fuel used combine the effects of changes in availability with those of changes in abun-

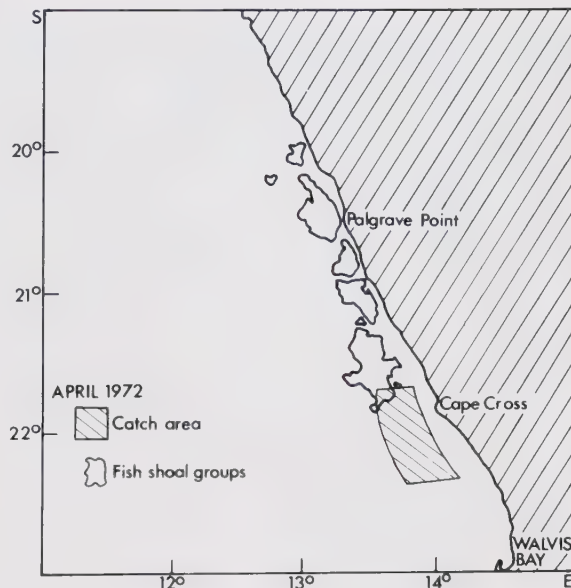


Fig. 3: Pilchard catch on southern end of shoal group (after Visser *et al.* 1973)

dance. As the phytoplankton community dominated by *Fragilaria karstenii* appears to be typically brown-green in colour, it is suggested that the CZCS may be able to discriminate between this and other communities. If so, then algorithms may be developed for the CZCS, to allow delineation of areas of potential absence of fish, and thus, it may be possible to incorporate a coefficient of availability into the CPUE index of abundance.

The largest source of data on fish occurrence is the fishing fleet, catch positions of which are all recorded. Comparison of catch position and ocean colour may allow the development of algorithms describing areas of high probability of fish occurrence, as has been done most effectively for the U.S. menhaden fishery in the Gulf of Mexico (Kemmerer *et al.* 1974).

From these two sources of information, the potential value of the CZCS to the management of the South West African pelagic fish stock can be demonstrated. Areas of high probability of pilchard occurrence may be delineated, allowing better strategic deployment of the fleet and so reducing expensive search time. Areas of low probability of fish occurrence can be determined and explained ecologically and these data used to refine population dynamics models.



Fig. 4: Part of a *Landsat-1* scene off South West Africa, showing a sub-surface feature identified as biological



Fig. 5: Part of a *Landsat-1* scene off the Cape West coast; inshore features identified as phytoplankton blooms or macrophytes or both



Fig. 6: Part of a *Landsat-1* scene including Walvis Bay; surface pollution from fish factories

EXISTING SATELLITE DATA

Variations in ocean turbidity deduced from digital data of the satellite *Landsat-1* have been compared with pre-existing fisheries oceanographical and remote sensing data in an attempt at identifying biological features off the south-west coast of Africa. The software used included VICAR running on an IBM 370 computer and several sets of purpose-written programs running on a UNIVAC 1106. Although oceanographic features have very low contrast in *Landsat-1* data, the studies have focussed attention on several remarkable features for which some form of ground truth is available in archives.

The large feature in Figure 4 is undoubtedly biological in origin and sub-surface. The brightest portion is 40 km long, and the ground-truth data suggest that it is zooplankton, chiefly euphausiids.

Figure 5 shows coastal phytoplankton blooms and benthic macrophytes or both off the Cape west coast.

Figure 6 shows pollution by organic material originating in the fish factories at Walvis Bay. In August 1973, very large landings of anchovies were made, which overloaded the factories. Anchovies soften rapidly and, when pumped with a "wet" off-loading system from the holds of vessels, tend to disintegrate. Large quantities of particulate and soluble organic material are lost under these circumstances, although the extent of pollution of the fishing grounds was unknown until now. "Dry" off-loading systems installed recently help to reduce this serious wastage of raw material.

CONCLUSION

Studies with existing data convincingly demonstrate that the detection of biological structures in the south-east Atlantic is quite feasible with *Landsat-1*. Because the CZCS of *Nimbus-G* is optimized for water, better results can be antici-

pated, and they could then be used to demonstrate the usefulness of the CZCS to fisheries management.

ACKNOWLEDGEMENTS

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FEASIBILITY OF ASSESSING THE SIZE OF THE SOUTH WEST AFRICAN PILCHARD STOCK BY COMBINED AERIAL AND ACOUSTIC MEASUREMENTS

I. HAMPTON, J. J. AGENBAG and D. L. CRAM

A method is being developed for determining the stock size of the South West African pilchard from night-time aerial measurements of shoal area combined with synchronous acoustic determinations of fish density within the shoals. An analysis of the possible errors in an aerial and an acoustic survey, conducted independently, suggests that by combining the two methods it should be possible to estimate the relative stock size with a precision of at least 50 per cent with 95 per cent confidence. It is estimated that the random errors and biases would contribute up to 20 per cent and 30 per cent respectively to the total error. Meaningful assessments of absolute abundance would probably be precluded by large uncertainties in any value assumed for the mean acoustic target strength of the fish.

'n Metode word tans ontwikkel ten einde 'n beraming van die Suidwes-Afrikaanse sardynstapel te verkry deur gebruikmaking van die visskool-area, soos deur nagtelike lugopnames bepaal, en die visdigtheid binne die skool, soos verkry uit 'n gelyktydige akoestiese opname. Onafhanklike analises van die moontlike foute in 'n lug- en 'n akoestiese opname het getoon dat deur 'n kombinerende van die twee metodes dit moontlik behoort te wees om die relatiewe stapelgrootte tot 'n akkuraatheid van ten minste 50 persent met 95 persent vertroue te bepaal. Na beraming sal ewekansige- en sydigheidsfoute respektiewelik tot 20 persent en 30 persent tot die totale fout bydra. 'n Betekenisvolle bepaling van die absolute populasiesterkte sal waarskynlik nie moontlik wees nie vanweë die groot onsekerhede in enige waarde wat aanvaar word vir die gemiddelde akoestiese teikensterkte van die vis.

An aerial method of making rapid assessments of the stock of the pilchard *Sardinops ocellata* (Pappe) in South West African waters has been developed by Cram (Cram 1972, 1974). A proposal has been made for improving the method by combining aerial measurements with synchronous quantitative acoustic measurements (Cram and Hampton 1976). The method is summarized briefly here for convenience.

An aircraft is used to locate and measure the area of pilchard shoals at night. The shoals are generally found in a number of well-defined groups and are detected by the visible bioluminescence which the fish stimulate in the water. The area of the shoals within each group is determined from measurements on a number of regularly spaced survey lines across the group. The shoal area on each line is measured from the fraction of the field of view covered by shoal luminescence along the line. This is either estimated directly by sight or is measured later from recorded low-light-level television images of the swath covered. A vessel operating simultaneously with the aircraft uses a calibrated echo sounder and a computer-based acoustic data-acquisition system (Hampton and Glaum 1974) to sample the target strengths of as many shoals in the group as possible, from which the mean weight of fish per unit area of the shoals is estimated by means of standard acoustic theory. Whenever possible, purse-seine catches are

made under aerial direction for species identification. The aerial estimate of the total area of the shoals is combined with the acoustic estimate of the mean weight (mass) of fish per unit area in the group to give the weight of fish in the group. The total tonnage of the adult stock is obtained by summing the weights for each shoal group.

This report is aimed at assessing the validity of the method from a critical evaluation of all error data available at present. As the method is still being developed and has yet to be fully implemented, this analysis should not be regarded as complete in any sense.

The possible statistical sampling error in the aerial estimate has been calculated from the variance in aerial measurements of five shoal groups surveyed during December 1972. Random sampling errors in the acoustic estimate have been determined by analysis of the variance in acoustic samples of shoal density taken from a single shoal group during February 1975. Possible sources of bias in both methods have been examined, where possible using quantitative arguments to assess probable ranges. Plausibility arguments based on research findings in the area are presented to support assumptions which are difficult to evaluate quantitatively. A number of assumptions cannot be evaluated at all from the data available at present and are accepted with reservation until fur-

ther work has been done.

AERIAL METHOD

Assumptions

The central assumption of the aerial survey method is that the horizontal boundary of a pilchard shoal is defined by the boundary of the bioluminescence stimulated by the shoal. This assumption is supported by a number of facts. In the Gulf of Mexico, Roithmayr (1970) found that individual Spanish mackerel *Scomberomorus maculatus* held in a net 3 m below the surface were clearly outlined by the stimulated bioluminescence of plankton occurring naturally in the water. Off South West Africa, it has been found that the incidence of shoal echoes recorded by an echo sounder on a ship passing through a bioluminescent area generally coincides with the edge of the bioluminescence visible from the ship. Bioluminescent patterns from individual shoals observed from the air have been seen to retain their shape over periods of up to 15 minutes, indicating that the patterns are related to the shoals, and that bioluminescence stimulated by species with different shoaling habits, such as pilchard and horse mackerel (maasbanker) *Trachurus trachurus* L., is characteristically different in pattern. Furthermore, on the few occasions that single shoal groups have been re-surveyed on successive nights, the agreement between the measured areas is comparatively good (Table I). This indicates that luminescence from shoals is sufficiently distinct from other luminescence (e.g. from waves and zooplankton swarms) to form a basis for abundance measurements.

Random errors

Because it is not possible to measure all shoals during one aerial survey, the population is sampled along a number of regularly spaced survey lines, introducing a random sampling error which increases with the degree of patchiness of the shoals. Other random errors occur in the physical measurement of the luminescent areas, mainly because of fluctuations in ground speed, navigational errors and errors in the measurement of the fractional cover of shoals in the field

Table I: Areas of shoal groups measured on replicate surveys

Group	Dates	Area of shoal group (km ²)
1	7 Dec. 1971	330
	8 Dec. 1971	332
2	15 Dec. 1972	535
	16 Dec. 1972	420*
	16 Dec. 1972	494*
	17 Dec. 1972	473
3	13 May 1972	767
	14 May 1972	481

*Surveyed twice on the same night (Fig. 1)

of view. The possible random error in the aerial estimate of the total visible luminescent area can be assessed statistically as follows. Let shoal group j be surveyed on N_j equally spaced east-west lines, ΔD_j apart. Let the length of line i be l_i and the fractional cover on line i be ρ_i . A_j , the area of the fish within shoal group j , can be calculated from:

$$A_j = \sum_{i=1}^{N_j} \Delta D_j l_i \rho_i$$

$$= \frac{D_j}{N_j} \sum_{i=1}^{N_j} l_i \rho_i$$

where D_j = distance between the first and the N_j th line for shoal group j .

It is assumed that D_j encompasses the limits of the shoal group in the north-south direction, and that the lines encompass the group in the east-west direction. The total area of the fish, A , is obtained by summing over all the groups:

$$A = \sum_{j=1}^M \frac{D_j}{N_j} \left(\sum_{i=1}^{N_j} l_i \rho_i \right)_j$$

where M is the total number of groups comprising the population.

If we assume that the navigation is sufficiently accurate for the errors in D_j to be ignored, the precision of A may be estimated from the distri-

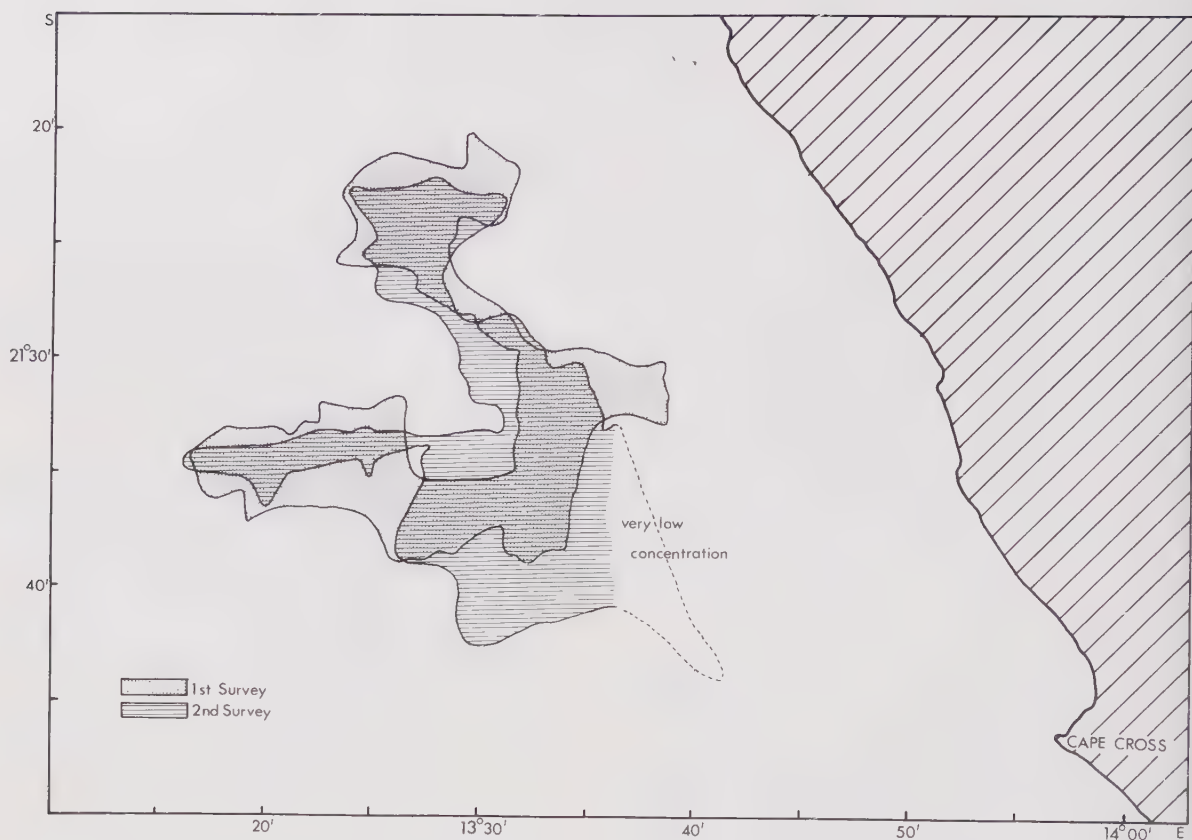


Fig. 1: Surface configuration of shoal group surveyed twice between 20h25, 16 April 1972 and 03h00, 17 April 1972

bution of the $(l_i \rho_i)_j$ values.

As an example, the standard error of $(l_i \rho_i)_j$, the mean of $(l_i \rho_i)_j$, for the shoal groups shown in Figure 2, has been calculated. The five groups were surveyed visually on 53 east-west lines averaging 2.4 nautical miles apart. The value of $(l_i \rho_i)_j$ was 0.26 nautical miles with a standard deviation of 0.16 nautical miles. A Chi-square test showed the distribution of $(l_i \rho_i)_j$ to be not significantly different from the normal distribution ($0.10 < P < 0.20$), so normal statistics were assumed. Since the values of $(l_i \rho_i)_j$ for adjacent swaths within the groups were weakly correlated (autocorrelation coefficient = 0.3), the standard error was calculated from the approximate expression of MacCall (1975):

$$S\bar{x} = \frac{S}{\sqrt{N(1-r^2)}}$$

where S = standard deviation in a single sample,
 $S\bar{x}$ = standard error of the mean,
 r = autocorrelation coefficient.

This gives $S\bar{x} = 0.023$, with a probability of less than 5 per cent that the mean differs by more than 20 per cent from the true value in the absence of bias.

It should be noted that the effect of increasing the survey swath width, d , would be to increase the size of the sample, and therefore the precision. If the swath was widened to a width of d' , introducing new observations uncorrelated with those obtained from the original swath, the standard error would be reduced by a factor of $\sqrt{d/d'}$. In practice, the improvement in precision will not be as great as this because of the correlation between the new and the original observations.

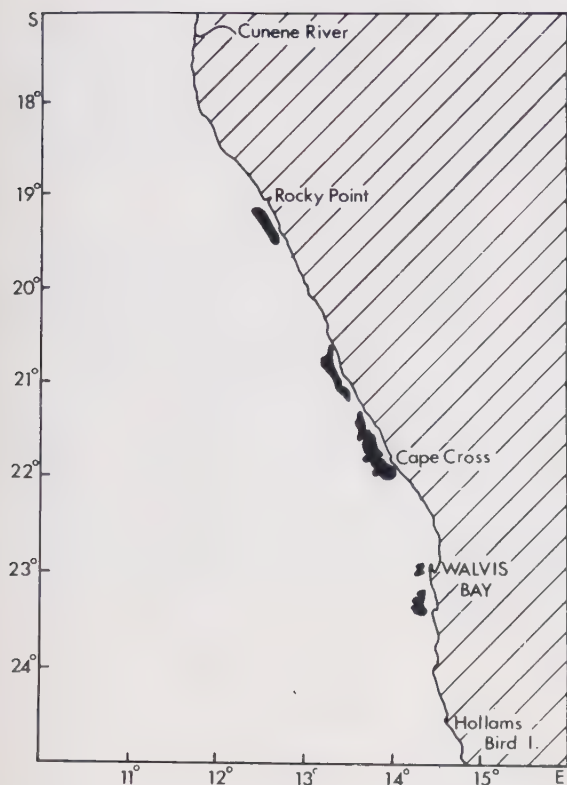


Fig. 2: Shoal groups determined by aerial survey, December 1972

Sampling bias

Visibility of the shoals – The method effectively requires that the whole fish population be visible from the air when viewing conditions are good, and assumes that the bioluminescent areas observed represent the horizontal areas of the shoal accurately. A number of possibilities for bias arise.

Shoals may be partly or totally invisible if the concentration of bioluminescent organisms in the water is too low. This is, however, not considered to be a serious source of bias, as it appears from the observations of Hart and Currie (1960), Kollmer (1962, 1963) and I. Kruger and D. J. Coetzee (Sea Fisheries Branch, personal communication) that there are sufficient luminescent forms present in the research area to indicate the presence of fish by bioluminescence. Luminescent dionoflagellates, believed to be the major contributor to natural biolumines-

cence in the ocean (Clarke and Kelly 1965, Tett 1971), occur widely throughout the year, together with luminescent copepods and radiolarians. It is noted that at no time during the year do aerial observers or fishermen experience prolonged difficulty in locating shoals by bioluminescence.

Laboratory work by Nicol (1958) suggests that luminescing organisms may become fatigued when continuously stimulated by a fish shoal. Therefore, as a shoal moves, the luminescence from its rear would be fainter, possibly causing an under-estimate of its area. In general, the luminescence from the shoal would be crescent-shaped with the head of the crescent in the direction of movement. Crescent-shaped luminescence from pilchard shoals has frequently been observed (Fig. 3), but this could be due to a characteristic moving shoal formation. No conclusive information has yet been obtained on bias due to plankton fatigue. This is an area for further research. Information is also lacking on whether shoals are ever so quiescent that they fail to stimulate sufficient bioluminescence to be detected from the air.

The shoals may be too deep to be seen from the air. From a comparison of the relative ability of aerial and shipboard observers to detect bioluminescence and a knowledge of the depth from which shoal bioluminescence can be detected at sea level, it is considered that under good aerial viewing conditions shoals can normally be detected to a depth of approximately



Fig. 3: Aerial picture of individual pilchard shoals taken by low-light-level television camera

10 m, whether by sight or with the low-light-level television camera. From echo recordings, it was found that the mean depth of 1 306 shoals in the research area between 20h00 and 06h00 on dark nights was 8,06 m with a standard deviation of 5,89 m (Fig. 4). No significant seasonal changes in depth were evident. A total of 24 per cent of the shoals were deeper than 10 m, although this is probably an over-estimate owing to the lack of data on shoals shallower than the transducer and to the tendency for shoals to sound when passing under the echo-sounder. When this information is combined, it is tentatively estimated that, under normal conditions, at least 80 per cent of the shoals should be detectable with the television camera. The argument is admittedly only semi-quantitative, but at least indicates that the problem of the shoals lying too deep to be detected is not so severe as to invalidate the method.

Pilchards that do not form well-defined shoals will not be seen from the air, and thus aerial estimates of abundance will be negatively biased. However, aerial observations, echo surveys and the experience of fishermen all show that pilchards form shoals throughout the year. Homogeneous shoals of 0-year-old pilchards are some-

times taken by commercial and research purse seiners, and it therefore seems probable that the major proportion of the adult stock is to be found in shoals. It should be noted that since the non-shoaling component is not available to the fishery, the aerial estimate is unbiased as an estimate of exploitable abundance.

Species mixing – When shoals of different species aggregate into a common shoal group, it is not always possible to discriminate between species when measuring luminescence on a swath across the group. As a crude first-order correction for this, the aerial measurement of shoal area is adjusted according to the percentage by weight of pilchards in purse-seine catches made on the shoal group at the time. The average percentage by weight of pilchards in 86 such research catches was 82,7 per cent (Fig. 5). It appears reasonable to assume that applying a correction should at least halve any error, in which case the residual error in the corrected estimate attributable to mixing of species would be less than 10 per cent.

Shoal movement – Since time limitations usually

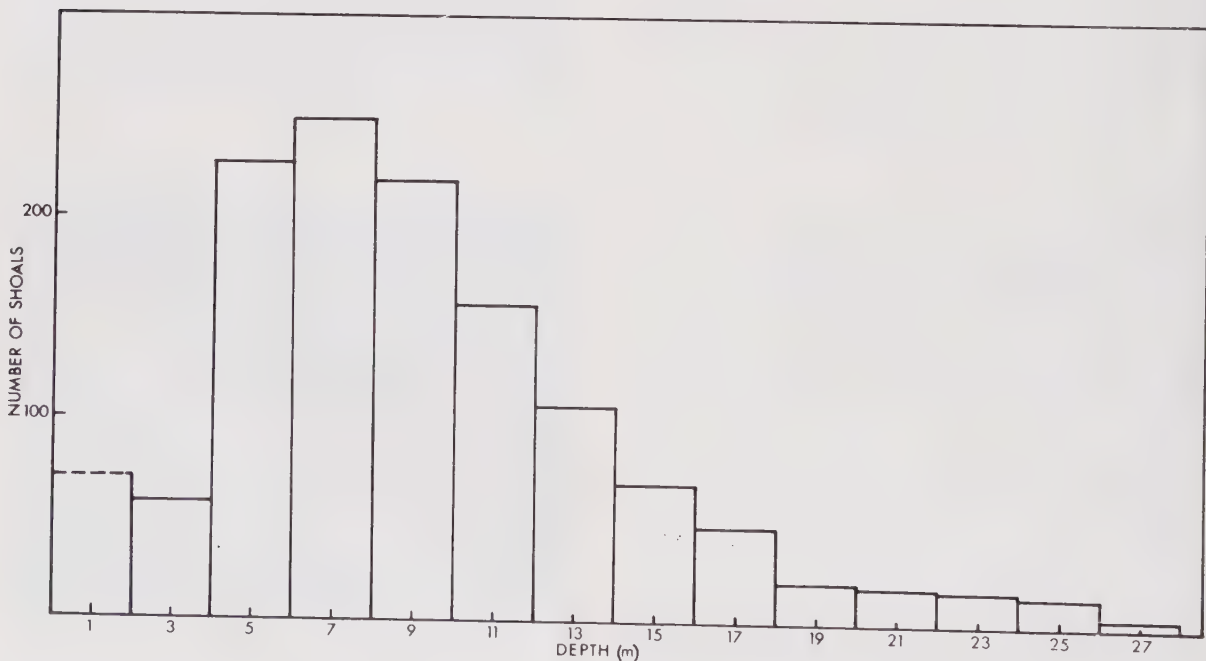


Fig. 4: Vertical distribution of shoals 20h00–06h00 (no moon)

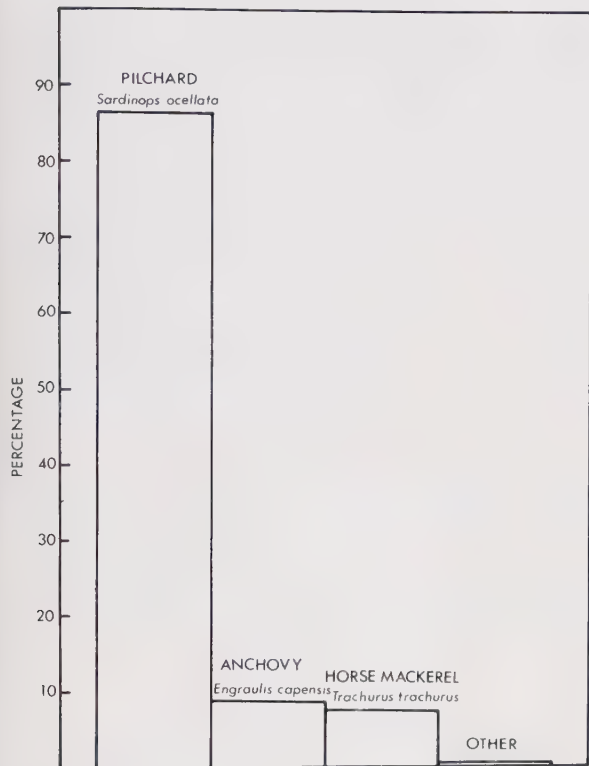


Fig. 5: Percentage composition by weight of species in experimental catches made within pilchard shoal groups (data by courtesy: F. H. Schüleln)

allow only one shoal group to be surveyed per night, the survey of all groups comprising the stock normally takes at least two weeks to complete, during which time they may move considerable distances (Fig. 6). Before an intensive survey on a particular shoal group is mounted, care has therefore to be taken to identify this group in terms of the distribution of all of the groups at the start of the survey, particularly after a break in continuity owing to, for example, poor flying conditions. Fortunately, this has not proved difficult to achieve in practice because the groups are generally well defined and isolated (Fig. 2) and maintain their integrity over many days (Figs. 7 and 8).

Measurement bias

With the direct viewer, the fraction of the field of view covered by luminescence is estimated visually at regular time intervals and classified in-

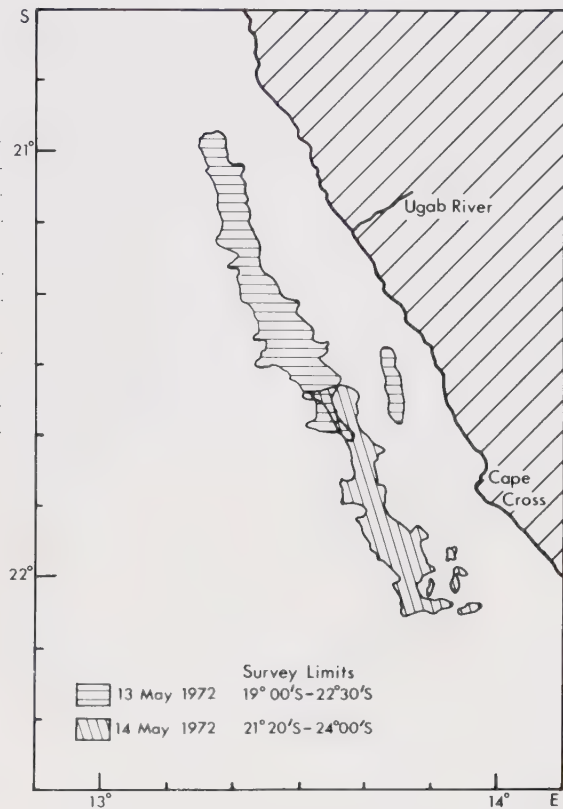


Fig. 6: Movement of shoal group in one day

to one of six categories varying from 0 to 100 per cent fractional cover. Misclassifications occur frequently, owing to the difficulty of making rapid subjective estimates, and if the observer consistently under- or over-estimates the fractional cover, a bias will be introduced. Measurements of luminescent areas on the television monitor screen may be negatively biased owing to the loss of weaker signals in noise, or positively biased owing to distortion of the image by lag effects in the tube (Cram 1974). Further systematic errors in the measurement of luminescent areas occur owing to, for example, refraction of the light from the shoals at the sea-air interface and distortions by the camera optics. These are, however, either negligible compared with errors already discussed, or could be corrected for should the overall precision of the method reach a point where these errors become significant.

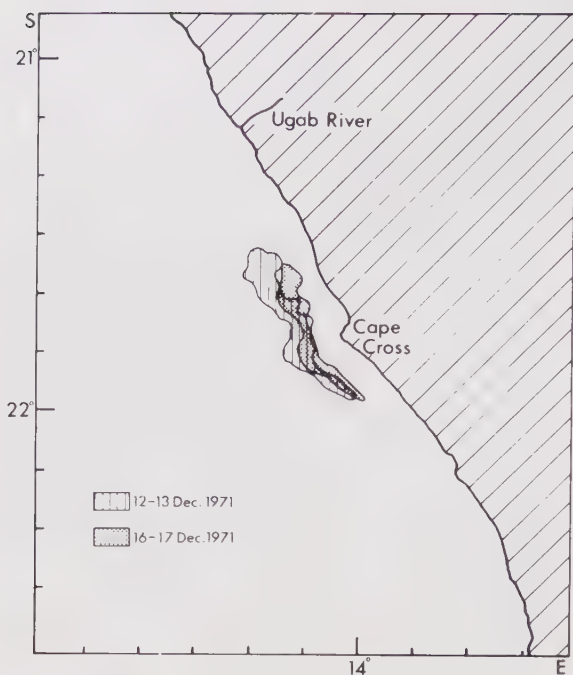


Fig. 7: Boundaries of shoal group four days apart

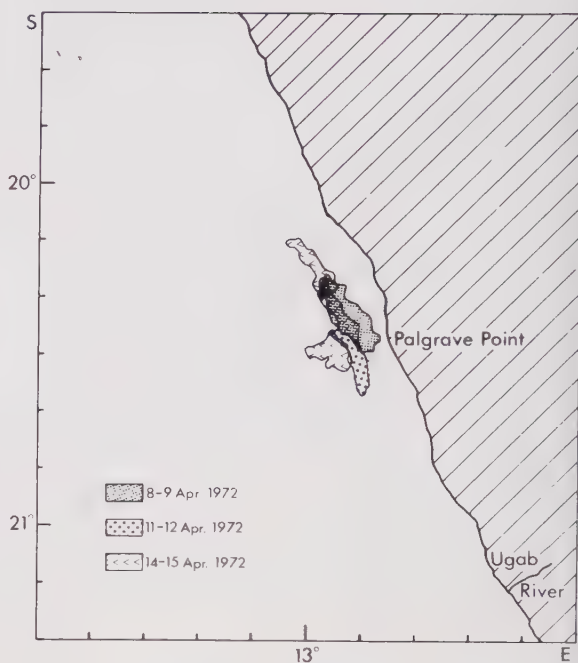


Fig. 8: Boundaries of shoal group over six-day period

ACOUSTIC METHOD

Basic theory

The rôle of the vessel in the method is to sample shoals within a shoal group while the aerial survey is in progress, thus gaining information on the mean surface density (weight of fish per unit area) of shoals within the group. Owing to the irregular shapes of the shoals and their patchy distribution, no attempt is made to assess the horizontal dimensions of either the individual shoals or the groups with the echo-sounder. The aircraft is much better suited to this task, having a field of view at least two orders of magnitude greater than the swath width surveyed by the echo-sounder at the depth of the fish.

The instantaneous intensity of a sound wave reflected from a shoal of fish at range R from the transducer is given by

$$I = \frac{k\bar{\eta} \omega e^{-2\alpha R}}{W\bar{R}^2}$$

where $\bar{\eta}$ = mean target strength of individual fish within the pulse volume,

ω = weight of fish per unit volume in the pulse volume,

$\bar{W}$ = mean weight of individual fish in the pulse volume,

α = absorption coefficient of sound at the carrier frequency,

k = transducer constant, depending on source level, beam pattern and pulse length.

For a fixed frequency,

$$\bar{\eta} \approx \beta \bar{W}$$

where β is a constant for a particular species (Goddard and Welsby 1977, Nakken and Olsen 1977).

Therefore,
$$I \approx \frac{k\beta\omega e^{-2\alpha R}}{\bar{R}^2}$$

If a time-varied gain of $20 \log R + 2\alpha R$ is used in the receiver,

$$\omega \approx \frac{Kv^2}{\beta}$$

where v = receiver output voltage,

K = constant for the electro-acoustic system.

The mean weight of fish per unit surface area, σ , between range limits R_1 and R_2 , is approximately given by

$$\sigma = \frac{KV^2 \Delta R}{\beta} \quad (1)$$

where $\Delta R = R_2 - R_1$,

V^2 = mean value of v^2 between R_1 and R_2 .

It is assumed that β is a constant between R_1 and R_2 , i.e. that the shoal is homogeneous between these limits.

If ΔR encompasses the vertical limits of all shoals encountered, the total weight of the stock can be estimated from the expression

$$W_T = A\bar{\sigma}$$

where A = aerial estimate of the total area of all shoals,

$\bar{\sigma}$ = mean weight of fish per unit area of the shoals averaged over all sound transmissions from which recognizable shoal echoes are received.

From equation 1,

$$W_T = \frac{CA}{N} \sum_{i=1}^N (V^2)_i$$

where C = a constant for fixed equipment settings and includes β which is assumed to be constant for all shoals,

N = number of sound transmissions.

Random errors

Even if the distribution of fish in the insonified volume is perfectly random, the value of σ for a single transmission will show a statistical deviation from the true value for the following reasons:

(i) The total acoustic energy reflected from the fish is a statistical quantity because of

the large number of configurations possible for targets of a given density. The different configurations are not equivalent because the acoustic beam is not of uniform intensity within the insonified volume.

(ii) Random phase interference occurs between echoes from individual fish in the pulse volume.

(iii) β is a random variable, mainly because of variations in the aspect of individual fish with respect to the transducer.

Assuming a three-dimensional Poisson distribution of fish in the insonified volume and an ideal-beam transducer (uniform intensity within the beam, zero elsewhere), δ , the expected coefficient of variation of σ , can be roughly estimated using the equation of Moose (1971),

$$\delta = \sqrt{\frac{c\tau}{2d} + \frac{\gamma_\beta}{\rho d\xi}} \quad (2)$$

where τ = pulse length,

c = speed of sound in water,

d = thickness of shoal,

ρ = mean number of fish/m³ for the insonified volume,

γ_β = target strength moment ratio accounting for variability of target strength,

$\xi = D(D+d)\pi \sin \theta_1 \sin \theta_2$, the average area of the beam between depths D and $D+d$, assuming a $\theta_1 \times \theta_2$ ideal beam.

For typical survey parameters ($\tau = 0.1$ ms, $d = 5$ m, $D = 5$ m, $\rho = 20$ fish/m³, $\gamma_\beta = 2.0$ (ex Moose 1971), and $\theta_1 = \theta_2 = 5^\circ$) the coefficient of variation would be 0.13. The contributions from the two terms in equation 2 are of the same order for these parameters.

If ρ is uniform throughout the population, the coefficient of variation of $\bar{\sigma}$ will be $\delta/\sqrt{N}$ where N is the number of insonifications. It is assumed that the overlap between insonifications is negligible so that samples of σ are statistically independent. The estimate of δ , from equation 2, is the lower limit and applies to the ideal case of uniform density throughout the population and of an ideal beam. In practice there will be large variations in ρ , both within shoals and from shoal to shoal, and the beam will not be ideal. The precision of $\bar{\sigma}$ will therefore be considerably less than suggested above.

A simple analysis of random errors was made by studying the variance in σ from data gathered

on an acoustic survey on a single shoal group in February 1975. Figure 9 shows the grid steamed and the approximate boundary of the shoal group determined by sonar mapping. The boundaries of the group were confirmed by aerial observation, although the precise area of the shoals could not be determined owing to severe fog over most of the region. The inshore lines were run as close to the coast as possible, but a number of the shoals were in water too shallow to be surveyed with the vessel. The acoustic data-logger was set to record echo signals over an adjustable 30-m depth range which encompassed all shoals detected. A 120-kHz transducer mounted on the hull was used throughout and the survey speed was 10 knots. If the echo level exceeded a pre-set threshold for more than four consecutive transmissions (corresponding to a distance of approximately 15 m), the target was taken to be a pilchard shoal unless the recorder trace was clearly uncharacteristic of this species. The analysis was restricted to the echoes from shoals. Since all instrument settings remained fixed, the variance in σ and $\bar{\sigma}$ were calculated from the variance in V^2 and $\bar{V}^2$ (the arithmetic mean of V^2) respectively. V^2 was calculated by numerical integration of v^2 , where v is the received output voltage, between 0 m and 30 m.

In order to test for diurnal changes in shoal surface density, the values of V^2 were grouped into two-hour intervals and plotted against time of day (Fig. 10). The mean surface density by day (06h00 – 20h00) was 4.3 times greater than at night (20h00 – 06h00). Because approximately the same area was surveyed by day and by night it was assumed that the day and the night samples were drawn from the same population and, therefore, that the diurnal difference in V^2 resulted from a widespread diurnal change in surface density of the shoals. The diurnal variation in shoal thickness was not marked (Fig. 10), showing that the increase in mean surface density during the day mainly resulted from an increase in the weight of fish per unit volume of the shoals. To correct for multipath scattering, which prolongs the duration of the echo and introduces positive biases in thickness measurements, the thickness of a shoal was taken as $R_2' - R_1'$, where

$$\int_{R_1'}^{R_2'} v^2 dr = \epsilon \int_{R_1}^{R_2} v^2 dr \quad (3)$$

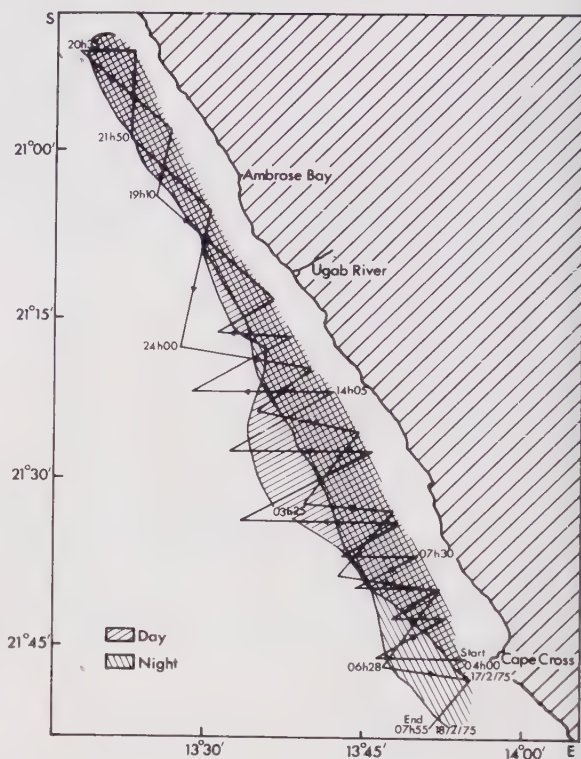


Fig. 9: Acoustic survey of shoal group, February 1975

The coefficient ϵ was adjusted to give values of $R_2' - R_1'$ which, on average, agreed with those estimated from the echo profiles (Fig. 11). The value of ϵ agreed on for our purposes was 0.95. It is worth noting that measurements of shoal thickness made from the wet-paper echo chart were highly biased, being up to twice as high as the corresponding values calculated from equation 3, even after subjective correction for tailing effects had been applied (Table II). This bias resulted from the poor dynamic range of the paper and the fact that the recorder responds to echo amplitude and not to echo intensity, thereby over-emphasizing the intensity of weak multipath echoes. It appears that, even with careful setting of the recorder sensitivity, large biases can arise if an echo-chart recording is used to determine the extent of a shoal in the direction of propagation of the beam. It is partly for this reason that sonar mapping techniques for the assessment of pilchard shoal size are not favoured here.

Because the mean surface density significantly differed between night and day, only values of V^2

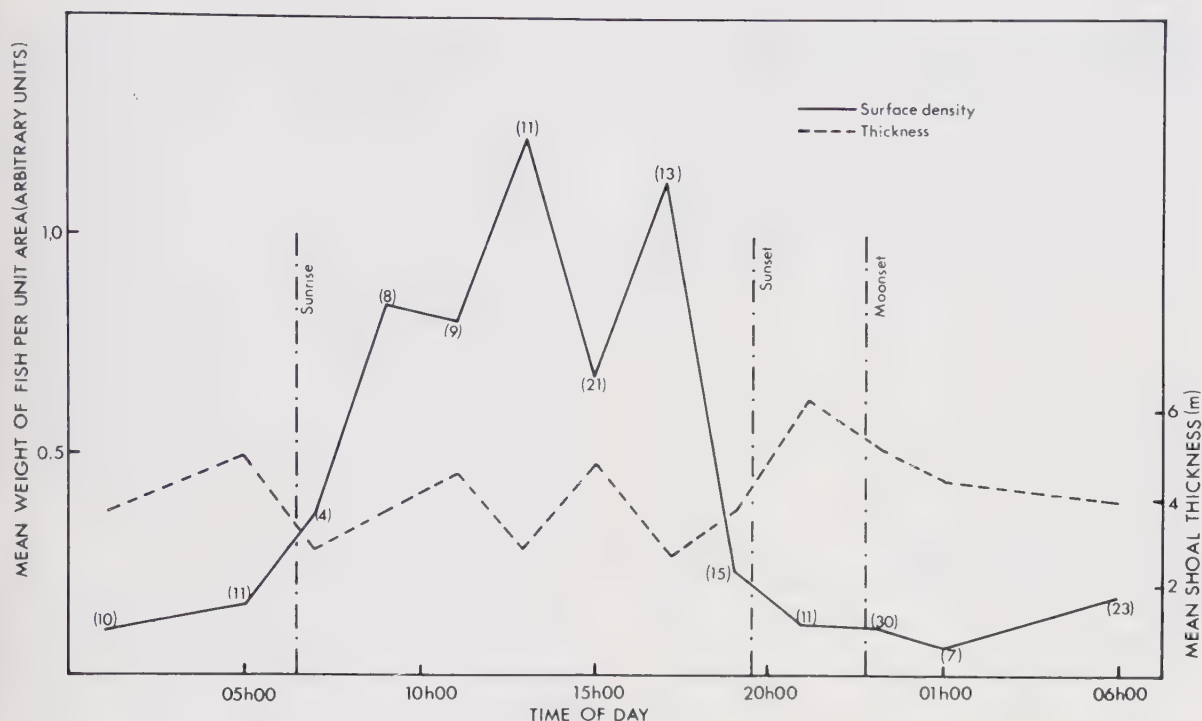


Fig. 10: Diurnal changes in shoal surface density and thickness, February 1975 survey (numbers in parenthesis indicate actual numbers of shoals encountered during each time interval)

Table II: Comparison of shoal thickness measured from echo chart and from echo envelope

Shoal	Mean thickness from echo chart (m)	Mean thickness from equation 3 (m)
1	9	4,37
2	9	6,35
3	8	6,31
4	11	5,42
5	5	2,94
6	5	2,46

Table III: Calculation of coefficient of variation of V^2 for a single transmission (untransformed data)

Number of shoals	Number of insonifications	$\bar{V}^2$	Standard deviation in V^2 $S(V^2)$	Coefficient of variation of V^2
92	1 976	0,155	0,190	1,23

recorded between 20h00 and 06h00 (i.e. night-time observations) were used in the variance calculation (Table III).

The distribution of V^2 was not normal, being highly positively skewed, but it was found that the distribution could be satisfactorily normalized by the transformation $Y = \log_{10} V^2$. The value of $\bar{Y}$ was -1,063 and that of S , the standard deviation, 0,476. A Chi-square test showed that the Y -distribution was not significantly different

from a normal distribution with this mean and standard deviation ($0,95 < P < 0,50$). The mean and the standard deviation of the untransformed data calculated from the moments of the Y -distribution by the functional relationships between the normal and log-normal distributions (Kenney and Keeping 1961), were 0,157 and 0,239 respectively, an agreement which is considered good.

Since Y is itself normally distributed with standard error $S_Y/\sqrt{N}$, the 95-per-cent confidence limits for $\bar{Y}$ are $\pm 0,021$. The corresponding limits for the geometric mean of the untrans-

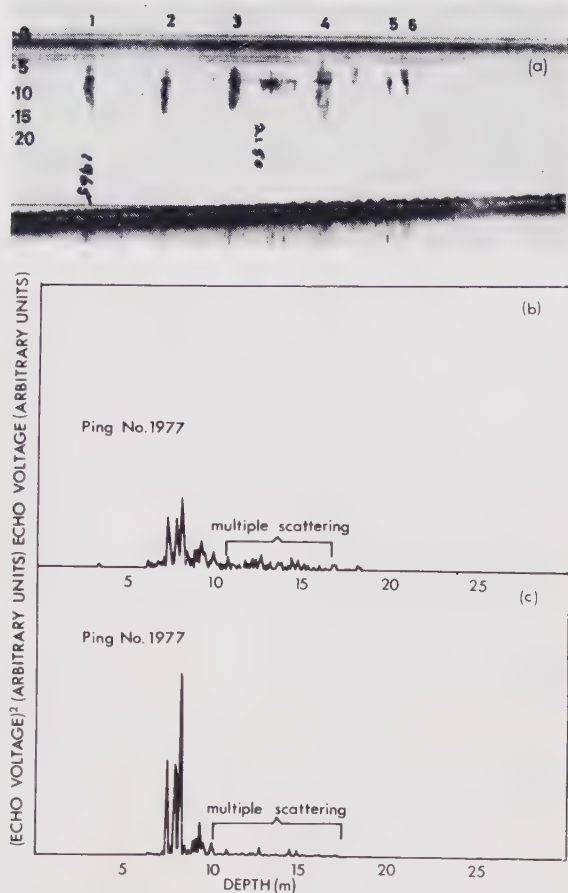


Fig. 11: Echo recordings of pilchard shoals: (a) echo-gram - shoal identification numbers (Table II) at the surface, (b) echo amplitude profile for a typical ping, (c) echo intensity profile of the same ping

formed data (antilog $\bar{Y} = 0,0865$) are 0,0824 and 0,0908 or approximately 5 per cent of the geometric mean. Finally, the assumption was made that the percentage error in the arithmetic mean $\bar{V}^2$ would also be ± 5 per cent at the 95-per-cent confidence limit. Although this assumption is not strictly correct (Bagenal 1955), these error limits are still better than those calculated directly from the untransformed data on the assumption that the distribution is normal. It is noteworthy, however, that the 95-per-cent error limits calculated without transformation are 0,0086 or 5,5 per cent of the mean, so that the assumption of a normal distribution would have

been justified in this case in spite of the fact that, where $S = 0,476$, $S(V^2)$ is only about 70 per cent efficient as an estimator of the standard deviation for the population (Finney 1941).

It is interesting that the coefficient of variation of V^2 is nearly ten times greater than that predicted from equation 2, a finding which indicates that the major causes of variance are real differences in average fish density within the insonified volumes and the use of a non-ideal beam. However, the good precision of the estimate of $\bar{V}^2$ suggests that variations in shoal surface density at night are not too great for a reasonable estimate of the relative mean to be made by sampling a small fraction of the shoals in the group, even with a series-production transducer. It is estimated from past aerial observations that the number of shoals analysed probably constituted fewer than 1 per cent of all the shoals in the group.

On a regular aerial-acoustic survey, the precision of the acoustic estimate would probably be better than that obtained on this experimental survey, because the ship would use sonar and information from the aircraft to sample as many shoals as possible each night. Also, the ship would not steam a fixed grid as in this case. If the total population is composed of M shoal groups, each giving approximately the same variance in V^2 , and if N samples are taken from each group, the standard error of $\bar{V}^2$ for the total population would be less than the standard error for a single group. The reduction factor would be approximately $M^{-1/2}$.

Bias

Estimates of $\bar{V}^2$ may be biased by a lack of samples from shoals shallower than the transducer. However, an analysis of the 92 shoals measured at night during the survey in February 1975 showed a 55-per-cent probability of no correlation between depth and $\bar{V}^2$ for a shoal, indicating that the bias from selected depth sampling would not always be serious. The shoal depths ranged from 3,1 to 12,0 m below the transducer.

Further bias would occur if shoals were either compacted or dispersed by the presence of the survey vessel. The magnitude of this bias is difficult to assess, although if it is assumed that shoals closer to the vessel react more strongly to it than those further away, the low correlation between $\bar{V}^2$ and shoal depth observed in February 1975 suggests that, on this survey at least,

the bias was small.

Non-random sampling errors may be introduced by the mistaken inclusion of echoes from shoals of other species. However, this is not regarded as a serious source of error because non-homogeneous shoal groups are uncommon (Fig. 5) and because aerial observations assist considerably in identifying shoals.

Multiple scattering and absorption of sound in dense shoals would introduce positive and negative biases respectively. Fortunately, the shoals appear to be less dense by night than by day, and these biases would therefore be at a minimum during the period that the vessel is working with the aircraft.

Errors in the values used for the system constant and the species coefficient β in equation 1 could introduce significant biases. For conventional echo-sounders, the chief sources of error in K are errors in the assumed transducer beam-pattern and the time-varied gain range compensation and distortion of the pulse envelope in the narrow-band receiver. These errors are purely physical and can, in principle, be reduced to acceptable levels by careful calibration and improved equipment. The coefficient β , however, may contain very large errors which are difficult to reduce, because the relationship between the weight and target strength of a small fish such as the pilchard is difficult to determine with any degree of precision. Therefore, acoustic estimates of the absolute value of $\bar{\sigma}$ (the mean weight of fish per unit shoal area) should be regarded as only semi-quantitative. However, relative estimates could be made without a knowledge of β , provided that its mean value remained constant. Although some variation in the mean of β might be expected for fish in different physiological condition, the range of these variations would be small compared with the uncertainty in the absolute value. In addition, if the equipment were calibrated frequently, relative errors in K could be kept small. Thus, the error in the relative estimate of $\bar{\sigma}$ should be determined mainly by the random errors and sampling biases already discussed.

Relative estimates of surface density combined with aerial estimates of the total area of the adult fish suffice to estimate the relative abundance of the adult stock. In an established fishery such as the pilchard fishery of South West Africa, where the impact of fishing on the stock has been studied over many years, relative estimates are sufficient for the regulation of fishing effort.

COMBINED ABUNDANCE ESTIMATE

If the aerial and the acoustic error estimates are combined, the possible error in a combined aerial acoustic measurement of pilchard biomass can be estimated. Admittedly, the fact that errors in aerial measurements from one survey have been combined with acoustic errors from another is unsatisfactory. This was, however, unavoidable because detailed analysis of acoustic data only became possible with the recent introduction of the digital data-logging system.

The random error in the aerial measurements of total shoal area within the five groups is taken to be 17 per cent (twice standard error) from the analysis of the December 1972 data. From the acoustic survey in February 1975, the random error in the relative estimate of $\bar{\sigma}$ for a single shoal group is taken as 5 per cent (twice standard error). If it is assumed that this would be typical for a shoal group and that each shoal group would be sampled with approximately the same intensity, the random error for the five groups would be approximately 2.2 per cent. This suggests that, in the absence of bias, the relative abundance of the stock could be estimated to within about 20 per cent at the 95-per-cent confidence limit.

Biases in both the aerial and the acoustic measurements are expected to fluctuate widely because most of them are due to biological factors. The aerial biases are largely additive, being predominantly negative. The largest single source of bias would probably be in the fraction of shoals invisible from the air. If it is assumed that a maximum of 20 per cent of the fish would be invisible during a survey and a tentative correction of 10 per cent were applied, the residual error would be unlikely to exceed 10 per cent. Doubling this to account for other sources of bias in the aerial estimate gives a tentative estimate of 20 per cent for additive biases. Most of the biases in the acoustic measurements could be either positive or negative, so some degree of cancelling should be expected. The largest source of bias in the absolute estimate of $\bar{\sigma}$ would be the error in the species coefficient β , but for relative estimates, biases arising from the reaction of the shoals to the vessel and the exclusion of surface shoals from the sample would probably predominate. Evidence has been presented to suggest that even these biases could be small, so the assumption of a total bias error of 10 per cent in the relative estimate of $\bar{\sigma}$ seems to

be reasonable.

From a combination of the estimates of random and non-random error, it is tentatively suggested that aerial-acoustic determinations of relative abundance could be made to within 50 per cent with the present system or logical extensions of it. The error limit calculated here applies to a single survey which could be completed in a month under good survey conditions. Between fishing seasons, there is sufficient time for a number of such surveys to be carried out to reduce the random-error component. Although the biases would not be reduced by repeated surveys, constant monitoring of all likely sources during combined surveys should make it possible to discover which sources of bias would most probably affect the total stock estimates. Crude corrections could possibly then be made. If the random error could be reduced to a negligible size by taking a large sample, the range of the bias could be estimated by comparing abundance estimates from surveys a short time apart.

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FIRST RECORD OF THE DINOFLAGELLATE *BRACHYDINIUM TAYLORII* SOURNIA IN THE BENGUELA CURRENT

I. KRUGER

The dinoflagellate *Brachydinium taylorii* Sournia, previously only found in the Mozambique Channel, has been recorded off South West Africa. The morphological features of the South West African specimen are compared with those recorded of specimens caught in the Mozambique Channel. Microplankton genera associated with *B. taylorii* off South West Africa are mentioned. The distribution and ecology of the genus *Brachydinium* and its associated microplankton taxa are discussed.

Die dinoflagellaat *Brachydinium taylorii* Sournia wat voorheen net in die Mosambiekkanaal gevind was, is nou ook aan die Suidwes-Afrikaanse kus ontdek. Die morfologiese kenmerke daarvan word vergelyk met dié van eksimplare gevind in die Mosambiekkanaal. Microplanktongenera wat saam met die Suidwes-Afrikaanse spesie voorkom, word genoem. Die verspreiding en ekologie van die genus *Brachydinium* en sy geassosieerde microplanktontaxa word bespreek.

In 1970, the Sea Fisheries Branch commenced a multidisciplinary research programme designed to investigate the decline in the stock of commercially exploited pilchard *Sardinops ocellata* (Pappe) in South West Africa. As part of this Cape Cross Programme, as it became known, routine collections of phytoplankton were made at specified positions on a grid, part of which is shown in Figure 1. The 17, 18 and 24°S lines were not covered in 1972.

Phytoplankton collections were made using an N50V Discovery-type net of 80 µm mesh size, drawn from 50 m to the surface where the depth allowed. Samples were preserved in 2-per-cent neutralized formalin in seawater for later processing ashore.

A notable record was of a dinoflagellate thought to be *Brachydinium taylorii* Sournia, one specimen of which was caught on 10 August 1972 at the off-shore station of the Rocky Point line (Fig. 1). The actual position of the station was 18°59,5'S; 11°25,5'E. The hydrological conditions encountered at the time of sampling (05h14) are shown in Table I.

DESCRIPTION

First described by Sournia (1972), *B. taylorii* appeared to be robust because of the thickness of the horns and the denticulate, thin, rib-like ridges which covered the surface of the cell. A description of the specimen from the Mozambique Channel follows. The anterior apical horn is short and broad and the posterior horns also

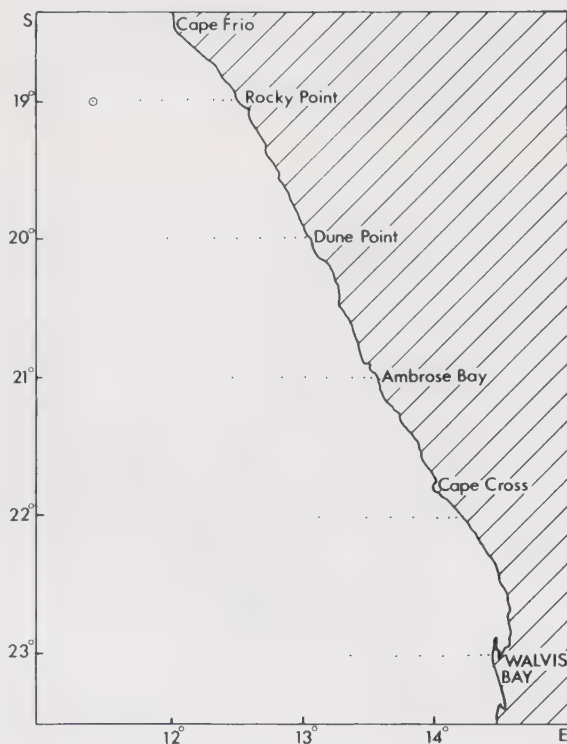


Fig. 1: Stations occupied during the environmental cruises of the Cape Cross Programme in 1972 (the position of capture of the specimen of *Brachydinium taylorii* Sournia is encircled)

broad but longer. The lateral horns, which are about 20 µm long, are narrow only at their tips. A globular nucleus is situated at the base of the

Table 1: Hydrological conditions encountered at the time of sampling

Depth	Temperature (°C)	Salinity ‰	Dissolved oxygen (ml/l)
Surface	15,97	35,44	5,45
50 m	14,92	35,35	5,26

left posterior horn. Sournia (*op. cit.*) was unsure of the number of chromatophores present in his specimen and indicated only a few. The diameter of the cingulum is 22 μm . No mention was made of the presence of flagella or of a longitudinal sulcus, both of which are normally present in dinoflagellates. In his description of the related *Brachydinium capitatum* Taylor, Sournia (*op. cit.*) mentioned that one flagellum had been observed by other workers and that movement had also been detected, indicating some means of locomotion in the members of the genus.

Features and measurements of the South West African specimen of *B. taylorii* (Fig. 2) agree fair-

ly well with those of the same species caught in the Mozambique Channel. Thin, rib-like ridges are just discernible on the upper part and the horns are similar in shape and position. However, the lateral and posterior horns are slightly longer (29 μm and 22 μm respectively) than those described by Sournia (1972) but the ratio between the lengths of the two is similar. A prominent globular nucleus is situated at the broader-based left posterior horn. The organism is densely packed with irregular chromatophores. The diameter of the cingulum is 28 μm and it can be seen as a narrow band apparently lacking in chromatophores. No sulcus or flagellum is evident.

ASSOCIATED ORGANISMS

The organism was associated with a mixture of 14 oceanic and 32 neritic diatom species of the

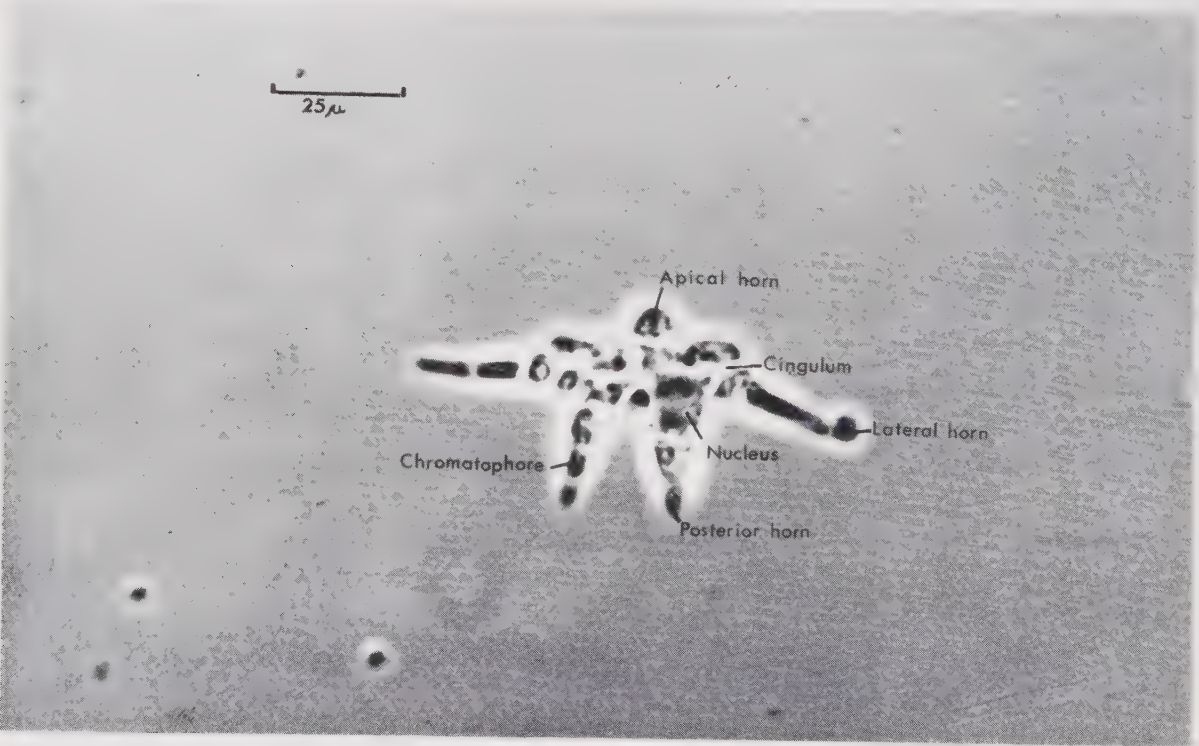


Fig. 2: Photomicrograph of *Brachydinium taylorii* Sournia (x 160)

genera *Stephanopyxis*, *Thalassiosira*, *Coscinodiscus*, *Planktoniella*, *Valdiviella*, *Corethron*, *Dactyliosolen*, *Rhizosolenia*, *Bacteriastrium*, *Chaetoceros*, *Eucampia*, *Biddulphia*, *Fragilaria*, *Thalassionema*, *Thalassiothrix*, *Asterionella*, *Nitzschia*, *Tropidoneis* and *Actinocyclus*. The tropical to subtropical blue-green alga *Oscillatoria thiebautii* was also present.

Apart from the diatoms, 39 other species were recorded. These included the dinoflagellate genera *Ceratium*, *Peridinium*, *Gymnodinium*, *Gonyaulax* and *Oxytoxum*, the tintinnid genera *Salpingella*, *Tintinnopsis*, *Proplectella*, *Dictyocysta*, *Eutintinnus*, *Rhabdonella*, *Xystonella* and *Epiplocylis*, the radiolarian genera *Sticholonche*, *Medusetta*, *Aulosphaera*, *Phormacantha*, *Clathrocyclas* and *Plectacantha* and the foraminiferan *Globigerina bulloides*.

Diatoms represented more than 99 per cent of the phytoplankton in the sample. Most of the microplankton species associated with *B. taylorii* off the South West African coast were also found in other localities where species of *Brachydinium* have been recorded, i.e. South-Western Indian Ocean (Taylor 1966, Sea Fisheries Branch unpublished data 1969), Mozambique Channel (Sournia 1970), Ligurian Sea (Léger 1972) and North-West Africa (Margalef 1973).

DISCUSSION

Sournia (1972) investigated both live organisms and specimens preserved in Lugol's sodium acetate solution. The difference in fixatives used and the fact that no live specimens were examined on the present occasion could have caused the slight difference in measurements. Overall, the organism shown in Figure 2 seems to be larger than that described by Sournia (*op. cit.*).

Species of the genus *Brachydinium* occur mainly off shore in the top 50 m of the warmer waters

around the African continent as indicated by Taylor (1963), Léger (1972), Sournia (1972), Margalef (1973) and also in this investigation. However, during the Combined Agulhas Cruise (12/3/69 – 22/3/69) *B. capitatum* Taylor was found on one occasion inshore in cooler water (13,38°C) at 33°51,5'S, 18°16,7'E where the continental shelf is narrow. On all other occasions that it was caught during the same cruise the water was warmer, with a temperature between 18,72°C and 24,65°C (Sea Fisheries Branch, unpublished data 1969).

It is significant that most of the species associated with *B. taylorii* Sournia from South West Africa also occur in other areas where this genus has been found. These associated species can be classified as being of cosmopolitan, temperate-tropical, inter-tropical and tropical-pacific origin and thus they seem to prefer the same general environment as the genus *Brachydinium*.

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FECUNDITY AND MATURITY OF ANCHOVY *ENGRAULIS CAPENSIS* OFF SOUTH WEST AFRICA

F. LE CLUS

The anchovy in South West Africa spawns mainly between November and March. Standard length at 50-per-cent maturity was 9,5 cm. Fecundity was investigated for anchovy collected during three spawning seasons: 1971/72, 1972/73 and 1974/75. Active-ripe ovaries contained two clear modes of yolked oocytes. The number of oocytes per fish was determined for both modes. The mode with the smaller oocytes contained 1,5 to 3 times more oocytes than the mode with the larger oocytes, called the last mode. In November 1974, anchovy smaller than 11,5 cm produced an average of $3,2 \times 10^3$ last-mode oocytes per fish, while anchovy 11,5 cm and longer produced an average of $6,3 \times 10^3$ per fish, but the number of last-mode oocytes per gramme of fish was similar for all length classes. Except for January-March 1972 the relative fecundity of fish 11,5 cm and longer did not differ between spawning seasons. The possibility is discussed that anchovy spawn twice within one spawning season.

Die anjovis in Suidwes-Afrika skiet kuit hoofsaaklik tussen November en Maart. Vyftig persent is geslagsryp by 'n standaardlengte van 9,5 cm. Fekunditeit is ondersoek vir vis wat gedurende drie kuitskietseisoene versamel is: 1971/72, 1972/73 en 1974/75. Dooierbevattende oösiëte van twee duidelike modale lengtes is in aktief-ryp ovaria gevind. Die aantal oösiëte per vis is vir beide modale lengtes vasgestel. Daar was 1,5 tot 3 keer meer van die groep kleiner oösiëte as van die modale groep groter oösiëte, genoem die laaste modus. In November 1974 het anjovis kleiner as 11,5 cm gemiddeld $3,2 \times 10^3$ oösiëte van die laaste modus per vis geproduseer en dié 11,5 cm en langer gemiddeld $6,3 \times 10^3$, maar die aantal oösiëte van die laaste modus per gram vis was soortgelyk vir alle lengteklasse. Behalwe in Januarie-Maart 1972, het die aantal oösiëte van die laaste modus per gram vis by vis langer as 11,5 cm nie tussen kuitskietseisoene verskil nie. Die moontlikheid word bespreek dat anjovis twee keer binne 'n kuitskietseisoen kan kuitskiet.

The South African anchovy *Engraulis capensis* Gilchrist occurs from Cape St Sebastian on the south coast of Africa to the Cunene River on the west coast (Pollock 1970).

The species makes a large contribution to the commercial purse-seine landings at Walvis Bay and Lüderitz in South West Africa, and at several ports around the south-western coast of South Africa. An enquiry into its reproductive potential is therefore vital to fisheries management and fecundity estimates are a first step in this direction.

Fecundity data have been published for other engraulids, e.g. *Engraulis mordax* (MacGregor 1968), *Engraulis japonica* (Usami and Sugiyama 1962) and *Cetengraulis mysticetus* (Peterson 1961). No fecundity results have yet been published for *Engraulis capensis*.

The purpose of this report is to present information on fecundity and maturity for anchovy collected off South West Africa.

MATERIAL AND METHODS

Collection of data

A total of 170 anchovies was obtained for fecundity determination from experimental catches made between November and April during three spawning seasons, 1971/72, 1972/73 and 1974/75 (Table I). The gonads of these fish were maturing. A large sample of routinely collected commercial fish augmented by smaller experimental catches in the closed season was used to calculate monthly gonad mass for the period 1970-1977. Length at maturity was determined from a total of 898 fish collected in December and January 1970-1974.

Method of fecundity determination

Fecundity was determined gravimetrically, only using yolked oocytes (active to ripe-running ovaries).

Table I: Catch data for anchovy

Spawning season	Period of collection	Catch locality	Number of fish
1971/1972	17 Jan.-19 Mar. 1972	19-20°S	14
1972/1973	10 Nov.-9 Dec. 1972	18-25°S	33
	10 Feb.-27 Mar. 1973	20-21°S	3
1974/1975	8 Nov. 1974	22°40'S	114
	13 Mar.-2 April 1975	22-23°S	6

For each fish, standard (caudal) length was recorded to the nearest millimetre and total fish mass to the nearest 0,1 g. The ovaries collected in 1972 and 1973 were slit open and preserved in Gilson's fluid (Simpson 1951) whereas those collected during 1974 and 1975 were preserved in formalin. Because Gilson's fluid macerates connective tissue, thus releasing oocytes from the ovary, and formalin preserves all tissue, two slightly different methods were used to prepare for further analysis.

In both methods, total ovary mass as well as that of subsamples was determined to the nearest 0,0001 g. The oocytes from ovaries preserved in Gilson's fluid were vacuum-dried in a modified Yashnov apparatus after removal of the ovary wall, and the total mass and that of subsamples were obtained (Le Clus 1977). For ovaries preserved in formalin, the masses of the total ovary and of two subsamples, one from each ovary, were determined. The subsamples were teased apart in a small volume of Gilson's fluid before counting the oocytes.

In active-ripe to ripe ovaries more than one mode of yolked oocytes was present. The larger, more advanced oocytes were called the last mode, while the mode smaller in length was called the intermediate mode. Usually the number of all yolked oocytes in each subsample was counted, but whenever it was possible to distinguish between two modes, only the oocytes in the last mode were enumerated.

The total number of oocytes in the last mode was calculated from:

Total number of last-mode oocytes =

$$\frac{(\text{Mass of all oocytes}) \times (\text{Number of last-mode oocytes in subsample})}{\text{Mass of subsample}}$$

The number of oocytes in the intermediate mode was derived proportionally from the size distribution. The lengths of between 200 and 300 yolked oocytes were measured at a magnification of X40 to obtain a representative distribution.

MATURITY AND SPAWNING SEASON

Spawning season

The spawning season of anchovy was deduced in three ways: from seasonal numbers of pelagic eggs (King 1977), from seasonal occurrence of

larvae (O'Toole 1977) and from monthly averages of gonad mass of males and females.

Egg collections were made from September 1971 to April 1972 but, although spawning occurred from October to April, anchovy eggs were not taken in large numbers until December (King 1977). The peak of spawning appeared to be February, spawning tailing off thereafter.

The occurrence of anchovy larvae was surveyed from August 1972 to March 1973 and from August 1973 to March/April 1974 (O'Toole 1977). Larvae were found in the plankton from November to March during the first survey and from October to April in the second. During 1972/73, 99 per cent of the total anchovy larva collection was made between December and March and during 1973/74, 96 per cent were taken during the same period.

Observations on spawning were supplemented by monthly information on gonad mass obtained between 1970 and 1977. Average gonad mass for males and females showed similar trends (Fig. 1). Gonad activity was low between May and September and high between November and March with peak activity in January.

These three sources of information together show that anchovy spawn from late spring to early autumn.

Length at first maturity

Resting ovaries cannot easily be distinguished from juvenile ovaries. It is, therefore, necessary to obtain data on length at first maturity only from the peak of the spawning season when it is assured that most adult fish would have active gonads.

Length at first maturity was ascertained from females and juveniles collected in December and January 1970–1974. The relative percentages of 898 juveniles and mature fish were plotted per 5-mm length class (Fig. 2).

In South West African waters, the anchovy apparently first matures at a standard length of 8,0 cm (Fig. 2). Fifty-per-cent maturity is attained at 9,5 cm which, according to Ratte (1973), would represent an age of 0+ years, and 100 per cent maturity at 11,0–12,0 cm. Anchovy spawn for the first time at the end of their first year, if 1 January is taken as the birthdate.

Maturity stages

In a typical immature ovary there are oogonia capable of mitotic division. These produce a

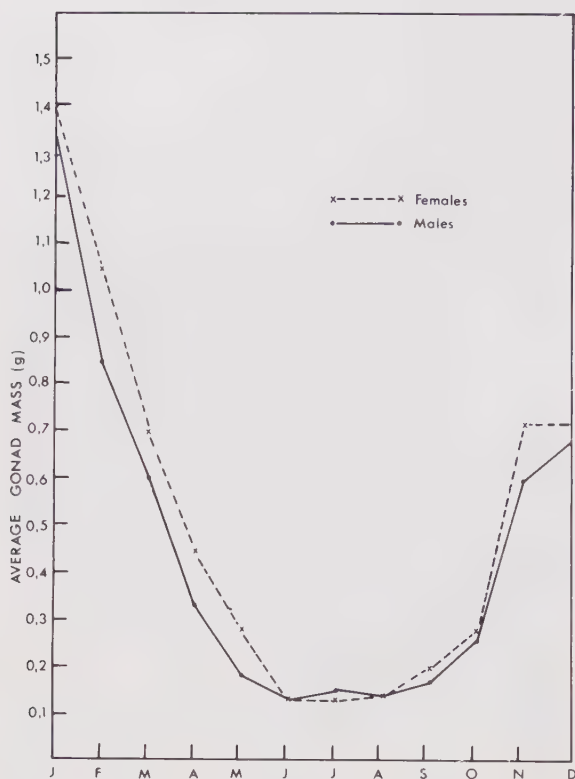


Fig. 1: Average gonad mass per month for males and females, 1970–1977

large number of diploid primary oocytes, i.e. female reproductive cells, which have lost their ability to divide mitotically (Balinsky 1975, Hilge 1975). The primary oocytes soon enter the first stages of meiosis. Meiosis continues until the late prophase of the first meiotic division and then ceases while yolk formation and oocyte growth continues until shortly before spawning. Thus, all yolked oocytes in active to ripe ovaries have not yet completed the first meiotic division and are still diploid. Meiosis is resumed shortly before spawning and the final maturation divisions of the oocyte which result in the fully mature haploid ovum take place after ovulation just before or even after spawning (Harder 1964, quoted by Hilge *op. cit.*).

Macroscopic features of ovaries should relate to microscopic changes in the oocytes. A short description of the macroscopic characteristics of the different stages in the development of the South West African anchovy is given in Table II. Seven maturity stages, similar to those described

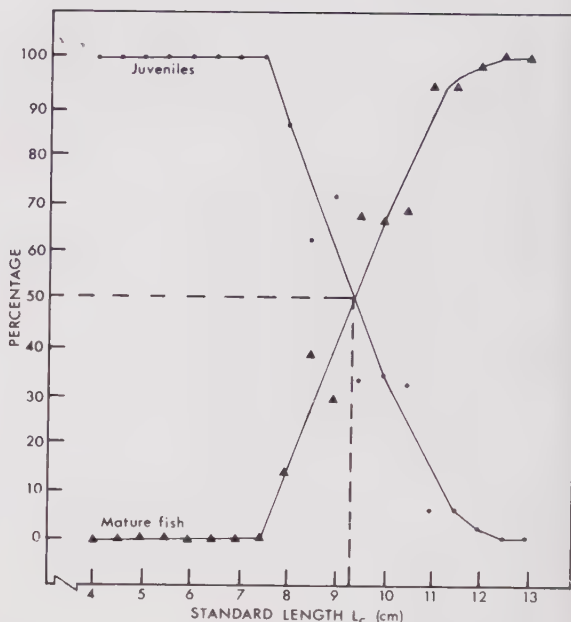


Fig. 2: Length at first maturity of anchovy collected in December and January, 1970–1974

by Davies (1956) for the pilchard *Sardinops ocellata*, were applied to anchovy ovaries. These stages were somewhat arbitrary. Blackburn (1950) encountered similar problems in defining stages of the Australian anchovy *Engraulis australis*.

Since the macroscopic classification is somewhat arbitrary, the microscopic classification based on the length distribution of the oval oocytes (Table III) did not always coincide with it. A description of the microscopic characteristics of the ovaries of *Engraulis capensis* is therefore given as a guide to the terminology used in the fecundity study. Only length ranges of yolked oocytes in active to ripe-running ovaries collected in November/December 1972 are used.

Active ovaries (Fig. 3a, b) – Ovaries with yolked oocytes longer than 0.20 mm were designated as active. Only late-active ovaries were collected for fecundity determination, two types being regularly found: unimodal and bimodal. (A polymodal ovary was found in the ripe-running stage only.) The size ranges of the largest oocytes found in unimodal and bimodal ovaries were similar (Table III) and, therefore, the ovaries can be assigned to the same maturity stage. In active bimodal ovaries, there was such an overlap be-

Table II: Macroscopic characteristics of maturity stages in the development of the ovaries

Stage	Macroscopic characteristics
1. (immature)	Virgin. Ovaries less than half length of the body cavity, thread-like, glassy or pale.
2. (inactive – active)	Refers both to immature fish commencing to mature and “recovering spent” fish. Ovaries are usually at least half the length of the body cavity. The immature ovaries are white, straw-coloured or glassy whereas the others are often distinctly bloodshot.
3. and 4. (active and active-ripe)	Pigmented, discrete oocytes are present. Ovaries occupy half to two-thirds of the body cavity respectively. Ovaries are pink, somewhat rounded, with a granular appearance due to the developing oocytes.
5. (ripe)	Ovaries are translucent yellow and almost fill the body cavity. About half the oocytes are translucent.
6. (ripe-running)	Translucent oocytes flow from the vent with slight pressure.
7. (spent)	Ovaries are generally still long but flaccid and reduced in bulk. Succeeded by stage 2 with which there is overlapping.

tween the two modes that it was not possible to count the last mode separately.

It is possible that from a basic stock of yolked oocytes a batch separates to mature to spawning (Fig. 3a, b). As will be seen, however, fecundity data do not give conclusive evidence in this respect.

Active-ripe to ripe ovaries (Fig. 3c, d) – The two modes become distinct once the smallest oocytes of the last mode have reached 0,45–0,55 mm in length and the largest oocytes,

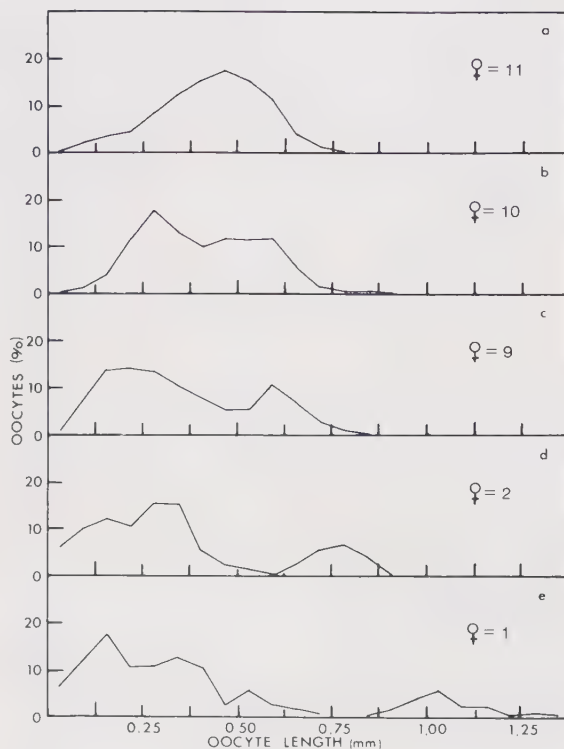


Fig. 3: Oocyte length distribution in different ovarian maturity stages: (a) active unimodal, (b) active bimodal, (c) active-ripe, (d) ripe, (e) ripe-running

0,79 mm – 0,92 mm (Table III, Fig. 3c). As the oocytes ripened, the separation between the last mode and the intermediate mode became more pronounced (Fig. 3d) seemingly as a result of faster growth rate of the last-mode oocytes. Minimum lengths of the last-mode oocytes at this stage were 0,67 – 0,73 mm.

Ripe-running ovaries (Fig. 3e) – In ripe-running ovaries, the last mode is completely separate

Table III: Microscopic characteristics of maturity stages in the development of the ovaries

Stage	Figure	Modal type	Oocyte size range (mm)			Number of fish	Date of capture (1972)
			Intermediate mode	Last mode	Largest of last mode		
3	3a	Unimodal	—	0,35–0,67	0,67–0,92	11	Dec.
3	3b	Bimodal	0,29–0,48	0,54–0,67	0,60–0,86	10	Nov./Dec.
4	3c	Bimodal	0,22–0,48	0,67–0,73	0,79–0,92	9	Nov./Dec.
5	3d	Bimodal	0,35–0,41	0,86–0,92	0,98–1,15	2	Nov./Dec.
6	3e	Polymodal	0,16 and 0,35	1,05	1,37	1	9 Dec.

Table IV: Fecundity data for 14 active-ripe anchovy captured in the period January – March 1972

Specimen	Standard length (mm)	Fish mass (g)	Ovary mass (g)	Last-mode oocytes		Number of intermediate-mode oocytes per g of fish	Total number of oocytes per g of fish
				Number (thousands)	Number per g of fish		
1	11,4	20,0	—	13,5	674	1 736	2 410
2	11,6	20,6	—	11,0	536	1 739	2 276
3	11,7	21,0	2,1	10,8	513	788	1 301
4	11,7	21,1	1,9	9,1	433	2 711	3 144
5	11,7	21,5	2,5	10,3	488	2 123	2 611
6	12,1	24,3	3,9	20,1	827	1 607	2 434
7	12,1	24,5	—	12,6	516	2 280	2 796
8	12,3	25,2	3,1	9,4	373	1 229	1 601
9	12,5	23,8	—	14,9	626	1 953	2 579
10	12,5	24,0	3,0	16,1	670	1 394	2 064
11	12,5	27,0	5,0	12,8	475	1 522	1 997
12	12,6	28,3	4,0	20,1	712	609	1 321
13	12,7	26,1	3,1	14,7	562	2 029	2 590
14	12,9	26,0	2,8	12,0	463	1 622	2 055

from the other modes.

A female with ripe-running ovaries was captured on 9 December 1972 near Sand Table Hill (19°40'S). This ovary was polymodal and the oocytes in the last mode showed further growth, their lengths ranging between 0,84 mm and 1,34 mm with a mode at 1,03 mm. The lengths of 31 anchovy eggs taken in plankton tows over the same period ranged from 1,1 mm to 1,6 mm with an average of 1,36 mm (Ratte, unpublished data). It appears, therefore, that the ripe-running ovary was collected shortly before spawning.

The intermediate-mode oocytes of the ripe-running ovary had attained a similar length range to that of the last mode of late-active ovaries (Fig. 3a, b) and it is assumed that these would normally have been spawned within a few months.

FECUNDITY

Selection of fish for fecundity estimation

When the fish were first collected for fecundity determination, the ovaries were classified into maturity stages which were based mainly on the size of the ovaries. The classification differed from that based on the length range of oocytes in the last mode. The yolked oocytes of all ovaries collected for fecundity determination were measured and counted. For the final fecundity estimates, ovaries were included only if the oocyte modes were distinct, and if the ovaries were not yet ripe-running, because in the latter case some of the ovulated oocytes may have

Table V: Fecundity data for 9 active-ripe anchovy captured in November/December 1972

Specimen	Standard length (mm)	Fish mass (g)	Ovary mass (g)	Last-mode oocytes		Number of intermediate-mode oocytes per g of fish	Total number of oocytes per g of fish
				Number (thousands)	Number per g of fish		
1	11,3	18,1	0,9	4,7	262	901	1 162
2	11,5	18,9	—	6,0	319	561	880
3	11,5	19,8	1,6	8,2	415	1 609	2 023
4	11,7	19,2	—	7,4	385	576	961
5	11,7	20,2	1,8	7,2	355	461	816
6	11,7	21,2	—	7,5	354	259	613
7	12,1	21,1	—	10,9	517	1 843	2 359
8	12,2	24,1	—	9,2	382	1 756	2 138
9	12,6	23,1	1,1	5,7	248	221	469

Table VI: Fecundity data for 6 active-ripe anchovy captured in March/April 1975

Specimen	Standard length (mm)	Fish mass (g)	Ovary mass (g)	Last-mode oocytes		Number of intermediate-mode oocytes per g of fish	Total number of oocytes per g of fish
				Number (thousands)	Number per g of fish		
1	11,8	17,9	0,8	6,6	371	328	699
2	12,0	19,2	0,8	8,4	436	440	876
3	12,4	18,8	0,9	8,9	476	1 300	1 776
4	12,5	18,6	1,0	9,4	507	612	1 119
5	12,5	20,8	0,6	6,2	297	753	1 050
6	12,6	20,0	1,0	9,3	463	425	888

been lost through pressure on the fish during capture.

Absolute and relative fecundity

Fecundity data are set out in Tables IV to VII. Data collected in January–March 1972 (Table IV), November/December 1972 (Table V), and March/April 1975 (Table VI) are given for individual fish, whereas data for 100 of the anchovy collected in November 1974 are given for each 5-mm length class (Table VII). Fecundity data are presented as both the number of last-mode oocytes per fish (absolute fecundity) and the number of last-mode oocytes per gramme of fish (relative fecundity).

Fish less than 11,5 cm long were collected in November 1974 and had an average of $3,2 \times 10^3$ last-mode oocytes per fish (Table VIII). Analysis

of variance of the four 5-mm length classes below 11,5 cm (Table VII) showed no significant difference in the average number of last-mode oocytes produced per length class ($F = 0,7$ for 3 and 86 degrees of freedom; $P > 0,05$). Anchovy 11,5 cm and longer produced an average of $6,3 \times 10^3$ last-mode oocytes per fish, i.e. nearly double that of the fish less than 11,5 cm long (Table VIII). The anchovy 11,5 cm and longer collected in November 1974 were grouped because of lack of data and compared with the fish of similar length distribution collected at other periods. The absolute fecundity was $13,4 \times 10^3$ in January–March 1972, $7,4 \times 10^3$ in November/December 1972 and $8,1 \times 10^3$ in March/April 1975 (Table VIII).

Therefore, the absolute fecundity of fish collected in January–March 1972 was about double that of the other periods. A statistical comparison between groups could not be made using the

Table VII: Fecundity data for 100 active-ripe anchovy captured in November 1974.

Length class (mm)	Number of fish	Data given as	Fish mass (g)	Ovary mass (g)	Last-mode oocytes		Number of intermediate-mode oocytes per g of fish	Total number of oocytes per g of fish
					Number (thousands)	Number per g of fish		
9,5–9,9	13	Mean	11,10	0,35	3,1	288	622	910
		SD	0,72	0,14	1,6	167	241	265
10,0–10,4	38	Mean	12,60	0,42	3,2	254	560	814
		SD	0,99	0,23	1,8	139	266	370
10,5–10,9	22	Mean	13,10	0,40	2,9	223	602	825
		SD	1,65	0,19	1,4	103	364	383
11,0–11,4	17	Mean	14,30	0,58	3,8	271	661	932
		SD	1,87	0,23	1,9	154	325	434
11,5–11,9	4	Mean	16,80	0,55	4,7	271	517	788
		SD	2,07	0,31	3,0	154	126	47
12,0–12,4	1	Actual	19,00	1,00	9,5	501	825	1 326
12,5–12,9	4	Mean	23,40	0,99	6,5	327	490	817
		SD	2,72	0,08	2,2	125	144	164
13,0–13,4	1	Actual	21,30	1,63	8,8	415	439	854

Table VIII: Comparative fecundity data from active-ripe ovaries for the period 1972 to 1975

Group sampled	Number of fish	Data given as	Last-mode oocytes		Number of inter- mediate-mode oocytes per g of fish	Total number of oocytes per g of fish	Percentage last-mode oocytes
			Number (thousands)	Number per g of fish			
January–March 1972	14	Mean	13,4	562	1 667	2 229	25
		SD	3,5	124	560	542	
November/December 1972	9	Mean	7,4	360	910	1 269	28
		SD	1,9	81	653	711	
November 1974							
Females < 11,5	90	Mean	3,2	255	598	853	30
		SD	1,7	136	296	367	
Females ≥ 11,5	10	Mean	6,3	331	470	861	38
		SD	2,8	137	192	192	
March/April 1975	6	Mean	8,1	425	643	1 068	40
		SD	1,4	77	356	377	

regression of absolute fecundity on standard length because the numbers were small, the length range was limited and the fecundity variation large. Statistical comparisons were made between groups of fish using the relative fecundity.

Before attempting a between-group comparison of relative fecundity, it was necessary to carry out a within-group comparison and the November 1974 fish were used for this purpose. Regression of relative fecundity on body mass and on standard length showed zero correlation with size. The relative fecundity data for November 1974 were analysed for fish above and below 11,5 cm standard length (Table VIII) because, with the exception of two individuals, the groups of fish collected at other times contained only fish above 11,5 cm. There was no significant difference between the larger and the smaller fish ($t = 1,7$; $P > 0,1$). Only the fish 11,5 cm and longer were therefore used when comparing the November 1974 sample with the others.

Relative fecundity has often been associated with condition index (K),

$$\text{where } K = \frac{\text{Fish mass in g} \times 100}{(\text{Standard length in cm})^3}.$$

The relationship between the two is presented in a semi-diagrammatic form in Figure 4, and the results of comparisons of relative fecundity by means of Student's t -test are also shown.

The relative fecundity of only the fish caught in January–March 1972 differed significantly from the others (Fig. 4). The other three groups – November/December 1972, November 1974, March/April 1975 – did not differ significantly from each other (Fig. 4). These results were unexpected, because it is often assumed that a

higher condition index should result in a higher relative fecundity. This was not found for the South West African anchovy. Although the condition index was higher in January–March 1972 than at other times, the condition index was nearly as high in November/December 1972 when the relative fecundity was low. In March/April 1975 and November 1974, the condition indices were similar to each other but both were much lower than that of November/December 1972, although relative fecundities in all three cases were of the same order.

Both relative and absolute fecundities were significantly higher in January–March 1972. This shows that fecundity varies from time to time for reasons as yet unknown.

The average relative fecundity for all active-ripe fish was 309 (SD 128). For anchovy less than 11,5 cm long, the average was 255 (SD 136), and for those 11,5 cm and longer, it was 435 (SD 109). The difference between the two size categories was statistically significant ($t = 7,3$; $P < 0,001$). If the dissimilar group, January–March 1972, is omitted, the relative fecundity of the larger group was 364 (SD 102). Compared with the relative fecundity of the smaller anchovy, the difference was again statistically significant ($t = 3,7$; $P < 0,001$). This finding seemingly conflicts with that arrived at earlier when it was found, for November 1974, that relative fecundity did not differ above and below fish lengths of 11,5 cm. It was not possible to differentiate between the fraction of the difference between small and large fish due to seasonal variation and the fraction due to the effect of the larger fish, because only one sample (November 1974) contained many fish smaller than 11,5 cm long.

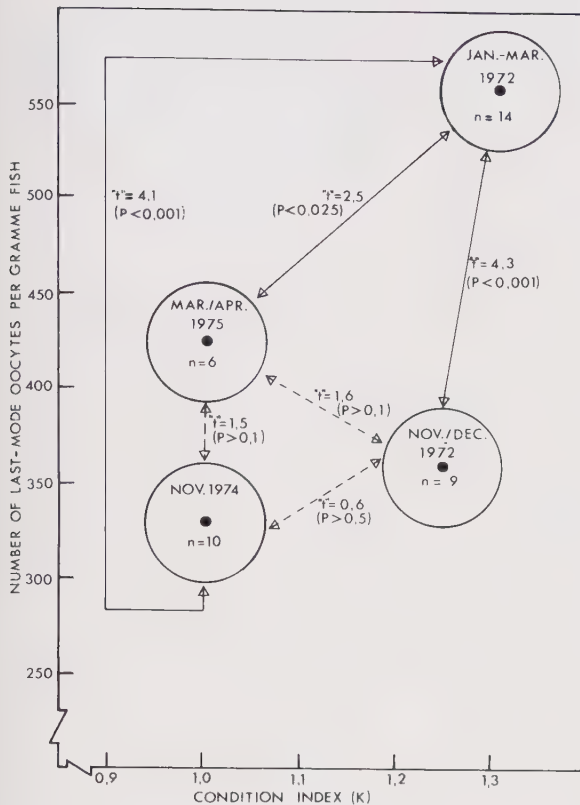


Fig. 4: Diagrammatic representation of relative fecundity at different times in relation to the condition index

Absolute fecundity and fish size

According to MacGregor (1968), the curvilinear relationship between standard length and absolute fecundity is unclear unless the largest fish in the sample is more than twice as long as the smallest fish. In the present case, the ratio was only 1.4:1 since the largest fish was 13.4 cm and the smallest 9.5 cm.

In order to clarify the relationship between absolute fecundity and fish size, the data were averaged per 1-mm length class (Fig. 5). Values from January-March 1972 were excluded because they were significantly higher than those of the other three groups. Where single values occurred, they were included in the next 1-mm length class.

Two clusters of fecundity values emerged, one below an average of 4.0×10^3 last-mode oocytes per fish and one above an average of 5.5×10^3 . The first cluster represented fish between 9.5 cm

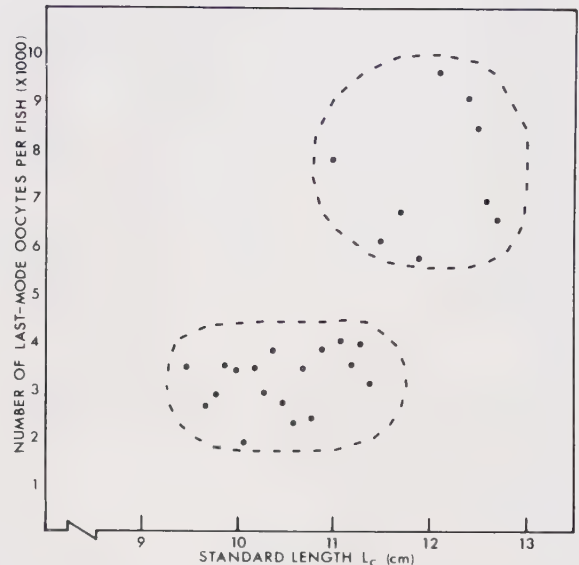


Fig. 5: Absolute fecundity of anchovy (in 1-mm standard length classes) for November/December 1972, November 1974 and March/April 1975 combined

and 11.5 cm long. According to their length, these fish were probably about one year old, spawning for the first time. The second cluster represented fish between 11.0 and 12.7 cm in length. These fish were probably two years of age or older. The results suggest that age, or more specifically the number of previous spawnings, may be important in determining the number of oocytes per batch spawned in the anchovy.

Because relative fecundity did not increase significantly with length, the increase in absolute fecundity could be better expressed in relation to increase in fish mass rather than to that in fish length. The increase in fish mass for the 4-cm length interval between 9 cm and 13 cm was 15 g, while up to 9 cm long the increase was only 7 g, as shown in Figure 6, where the average annual mass of commercially landed fish per 5-mm standard length class is plotted for the period 1970 to 1977.

The direct relationship between fecundity and fish size is presented only for the 100 active-ripe females collected in November 1974. The other samples were too small and the variation in oocyte number too large for the results to be acceptable.

The relationships between fecundity and standard length and between fecundity and fish mass were depicted by means of linear regressions of

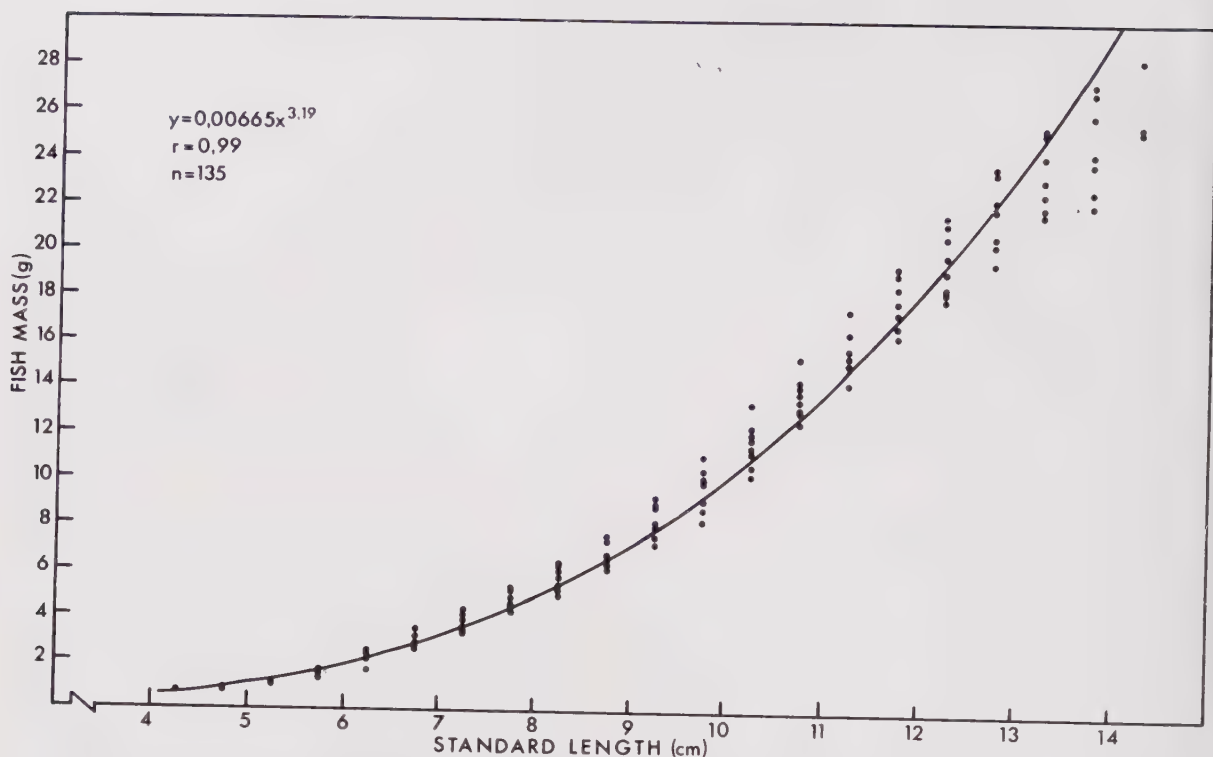


Fig. 6: Relationship between standard length and fish mass from annual averages, 1970–1977

the form $Y = MX + C$ (Figs. 7 and 8), where Y represented the dependent variable (fecundity), X the independent variables (standard length or fish mass) and M and C were constants. However, the correlation between fish size and the number of last-mode oocytes produced per fish was poor. According to MacGregor (1968), this may have resulted from the production of oocytes within a relatively short length-range of fish and the great variation in numbers of oocytes produced at each length or mass – conditions that apply to the anchovy (Figs. 7 and 8).

SERIAL SPAWNING

Individual anchovy in South West Africa may be able to spawn twice, both early and late in the season. This possibility is suggested, in active-ripe ovaries, by the large reserve of intermediate-mode oocytes (60 to 75 per cent of the total

yolked oocytes), apart from the last mode, which are found throughout the extended spawning season (Table VIII). The situation in the early part of the season, for instance November/December 1972 and November 1974, is particularly relevant to an investigation of serial spawning.

Active ovaries were, with the exception of three in February/March 1973, only collected in November/December 1972 and in November 1974, and present information that further helps to clarify the periodicity of reproduction in the South West African anchovy.

The active ovaries collected in November 1974 were different from those collected in November/December 1972 because 9 out of 14 were classified macroscopically as “recovering” (i.e. between spent and active). They were reclassified as “active” after the yolked oocytes had been measured. A further difference was that only one mode of yolked oocytes was present. However, some ovaries contained a few large oocytes which could have been the remnants of a spawning shortly before. Therefore, it is possible that

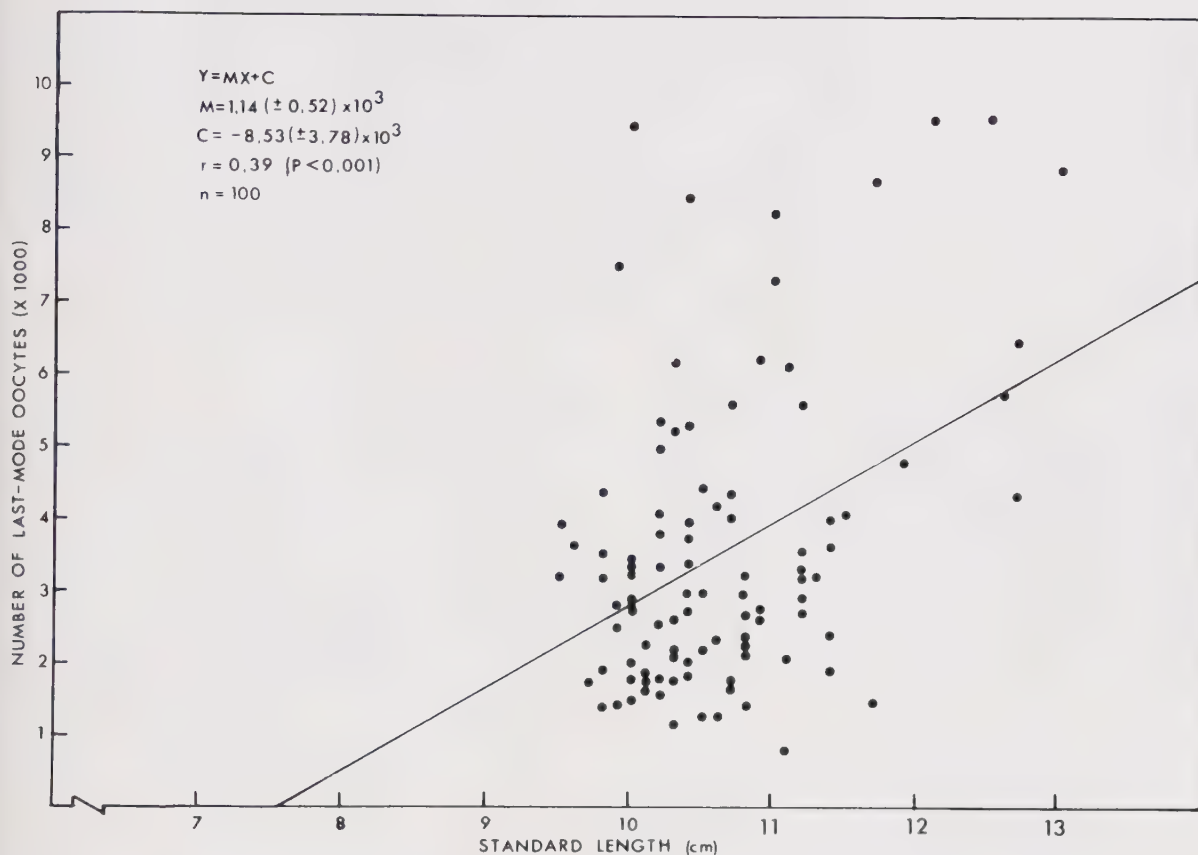


Fig. 7: Relationship between absolute fecundity and standard length for 100 anchovy collected in November 1974

the fish had spawned recently and that the remaining yolked oocytes were in the process of developing for a second spawning later in the same season. This suggestion was substantiated by comparing the relative fecundity of these fish with that of fish collected later in the same spawning season. The relative fecundity of the active ovaries in the early part of the spawning season (November 1974) was similar to that of the last mode of active-ripe ovaries in the later part of the spawning season (March/April 1975). The relative fecundities were respectively 428 (Table VIII) and 425 yolked oocytes per gramme of fish (Table IX).

The relative fecundity of the unimodal "active" ovaries of November 1974 was also equivalent to that of intermediate-mode oocytes of the distinctly bimodal active-ripe ovaries of fish over 11.5 cm in length caught in the same month

($t=0.59$; $P>0.05$). This indicated that the unimodal "active" fish could be linked with the active-ripe fish not only as successive maturity stages but also as successive spawning stages – the first group having been caught just after spawning and the second group shortly before spawning. The yolked oocytes of the "active" ovaries and the yolked oocytes of the intermediate mode would represent the material available for a second spawning later in the same season, namely March/April 1975, as has been shown for the "active" ovaries.

An apparent discrepancy has to be explained. The relative fecundity of intermediate-mode oocytes of active-ripe ovaries of fish smaller than 11.5 cm was significantly higher than that of the unimodal "active" ovaries ($t=2.10$; $P<0.05$). However, there was no difference in relative fecundity of intermediate-mode oocytes between

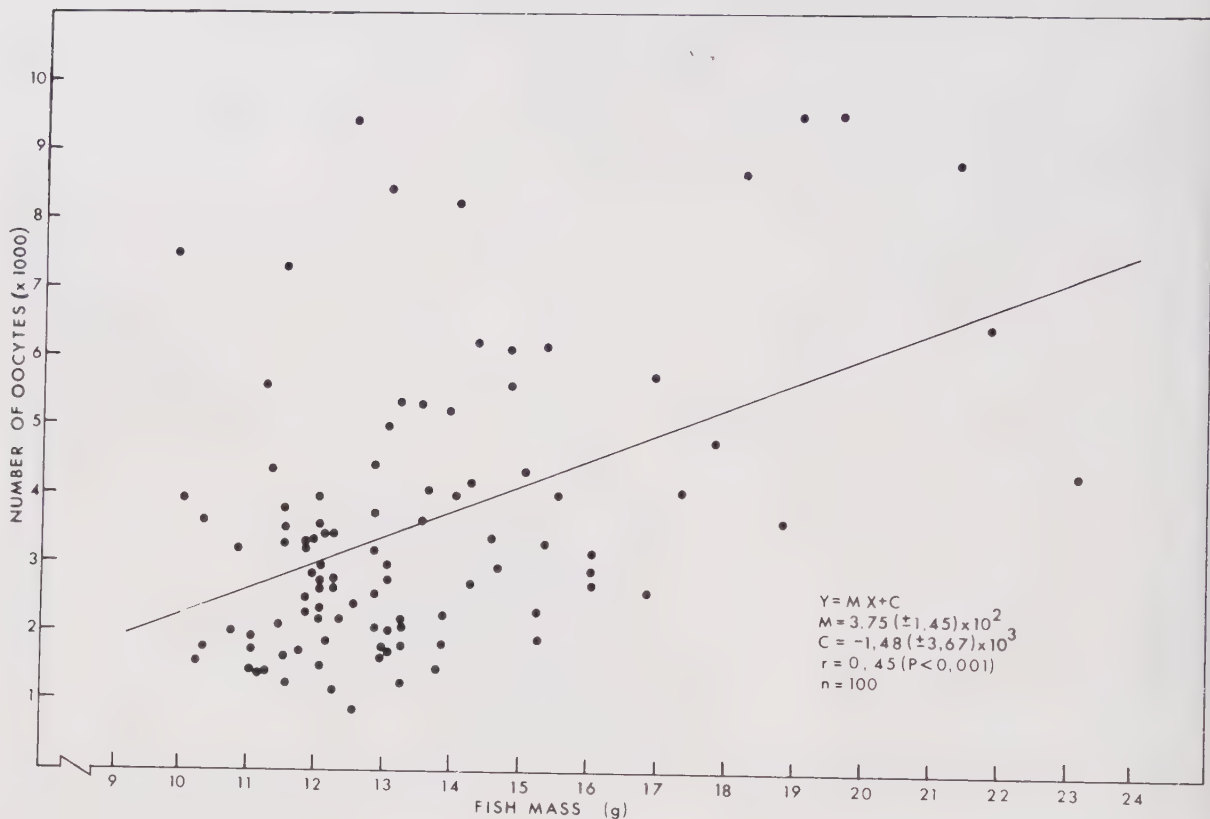


Fig. 8: Relationship between absolute fecundity and fish mass for 100 anchovy collected in November 1974

active-ripe fish smaller and larger than 11.5 cm ($t = 1.33$; $P > 0.05$). All three relative fecundities represent estimates of the same population mean ($F = 2.96$; $P > 0.05$), so that the arguments for serial spawning remain valid.

The clearly bimodal active-ripe ovaries of November/December 1972 may be analogous with those collected in November 1974, and it is therefore possible that these fish could have spawned in late December or early January and again before the end of the spawning season in March/April. The three fish collected in February and March 1973 were active and could therefore not be used to substantiate the possibility of a second spawning.

The active ovaries collected in November/December 1972 may further illuminate the maturation process in the anchovy (Fig. 3a, b). The active ovaries contained either a single mode of yolked oocytes or two overlapping modes of yolked oocytes. Only one of the active

ovaries had previously been classified as "active possibly recovering". This unimodal ovary had remnants of oocytes from a previous spawning. One of the bimodal active ovaries also contained a few large oocytes. Both unimodal and bimodal active ovaries could therefore be found after the first spawning.

The relative fecundities of total yolked oocytes (Table VIII) were similar for both unimodal and bimodal active ovaries ($t = 0.79$; $P > 0.05$). From this observation it can be deduced that the last mode splits off from a single mode of yolked oocytes (Fig. 3a, b), the remaining yolked oocytes forming the intermediate mode. However, when the total numbers of yolked oocytes in the active and active-ripe ovaries of November/December 1972 were compared, the relative fecundity of the active-ripe ovaries was significantly higher ($t = 4.98$; $P < 0.005$). From this finding it is inferred that the intermediate mode of yolked oocytes, which ori-

Table IX: Relative fecundity data for active ovaries

Group sampled	Modal type	Number of fish	Date given as	Standard length (mm)	Number of yolked oocytes per g of fish
November/December 1972 and February/March 1973	Unimodal	12	Mean	12,01	534
			SD	0,23	198
	Bimodal	12	Mean	11,85	474
			SD	0,47	174
November 1974	Unimodal	14	Mean	10,48	428
			SD	0,48	156

ginated as the remaining yolked oocytes after the last mode had separated from the common stock, is supplemented in active-ripe fish by non-yolked primary oocytes entering vitellogenesis.

The anchovy can therefore be assumed to be a potential serial spawner, the same fish spawning early and later in the spawning season. Peaks of spawning could vary from year to year, depending on environmental conditions. In addition, the anchovy spawns over extended periods, so that not all fish become ripe at the same time. Individual fish may possibly spawn either once or twice within the spawning season depending on environmental and/or physiological factors.

DISCUSSION

Anchovy have two modes of yolked oocytes in active-ripe ovaries. Only the mode with larger oocytes was considered to represent the maturing oocytes, and was called the last mode.

The last mode appears to split off from a more numerous group of yolked oocytes (Fig. 3) and may not be derived as a group directly from primary oocytes. Only in the later stages of maturation at the active-ripe stage were two distinct modes observed. This means that a second group of yolked oocytes could mature shortly after the first one and may explain why peaks in spawning could occur in December and again in February (King 1977). The argument is not valid if two separate spawning stocks occur.

Absolute fecundity increased in proportion with both fish length and mass (Figs. 7 and 8). Relative fecundity was, however, similar for all 5-mm length classes within the only sample that contained both large and small fish.

Fecundity values were obtained for the 1971/72, 1972/73 and 1974/75 spawning seasons, and

except for anchovy collected in January-March 1972, the relative fecundities of the different groups were similar for fish longer than 11,5 cm.

The highest average relative fecundity was 562 oocytes per gramme of fish for 14 anchovy collected in January-March 1972. This value is similar to that of MacGregor (1968) who found 574 oocytes per gramme of fish for 19 *E. mordax*. However Peterson (1961) found much higher relative fecundity values for 86 *Cetengraulis mysticetus* (836 oocytes per gramme of fish).

The lower value of average relative fecundity obtained for nine active-ripe *E. capensis* collected in November/December 1972 (360 oocytes per gramme of fish) was close to that quoted by MacGregor (1968) for seven *Anchoa naso* (326 oocytes per gramme of fish).

There is no conclusive evidence of serial spawning in anchovy. There is, however, some circumstantial evidence. Some active ovaries collected in November 1974 contained a few large oocytes which may have been the remnants of a spawning shortly before in addition to a residual mode of developing yolked oocytes. It is, therefore, presumed that even the members of the batch that contained no ovulated oocytes had spawned and that their yolked oocytes were residual and developing for a later spawning. This assumption is strengthened by the fact that the total number of yolked oocytes in these ovaries was similar to the number of last-mode oocytes of active-ripe ovaries collected later in the same spawning season, in March/April 1975 (Tables VIII and IX).

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THE FOOD OF THE SNOEK *THYRSITES ATUN*

C. S. DE V. NEPGEN

The snoek *Thyrsites atun* is a voracious carnivore, which feeds on a variety of fish, crustaceans and molluscs. Fish, particularly pelagic fish, were the main component of the diet. The stomachs of handline-caught and trawled snoek were examined and the prey species listed. The frequency of occurrence of main food items in the diet of handline-caught snoek is tabulated, showing that pilchard and anchovy predominated. In trawled snoek, lantern-fish and juvenile hake were most important. Euphausiids were more often recorded in the stomachs of trawled snoek. The mass of individuals of prey species varied considerably and the composition of the diet is shown to be largely dependent upon availability of particular food organisms at a given time.

Die snoek *Thyrsites atun* is 'n gulsige karnivoor wat van 'n verskeidenheid visse, skaaldiere en weekdiere leef. Vis, veral pelagiese vis, is die hoofbestanddeel van sy dieet. Die pensinhoud van snoek wat met handlyne en in bodemtreilnette gevang is, is ondersoek en die prooispesies getabelleer. Die voorkomfrekwensie van die hoofvoedselitems in die dieet van snoek wat met handlyne gevang is, word aangegee; daarvolgens oorheers sardyn en ansjovis. By treilsnoek was lanternvis en jong stokvisse die belangrikste. Eufausiiede is meer dikwels in die pense van treilsnoek genoteer. Die massa van individue van die prooispesies het heelwat gewissel, en daar word aangetoon dat die samestelling van die dieet hoofsaaklik van die beskikbaarheid van besondere voedselorganismes op 'n gegewe tydstop afhang.

The snoek *Thyrsites atun* (Euphrasen) is of considerable economic importance in South Africa, especially to the Western Cape line fishermen who catch between two and three million each year. The Sea Fisheries Branch has made experimental catches of snoek since 1958, and diet has been one of the aspects studied. Altogether the contents of 2 971 stomachs were examined, most being collected off the Cape Peninsula.

The snoek stomach has a rugose inner lining folded longitudinally, which indicates an ability for considerable distention and, probably, rapid digestion. Methods in which only volume or weight (mass) is used to analyse the stomach contents may present a very inaccurate picture, for the time lapse between feeding and capture of the fish would affect the results considerably. Because of this, only the incidence of the species in the stomach contents was noted.

The teeth of the snoek are sharp and pointed inwards, which indicates that they are not for masticating. Therefore, most of the food items found in the stomachs were swallowed whole although some were much digested by the time they were examined. In some cases, the contents were so digested that fish remains could only be identified by examination of the less digestible otoliths.

Of 2 815 stomachs from handline-caught snoek and 156 from trawled snoek examined between 1958 and 1974, 58 per cent and 44 per cent respectively were empty.

The following items were found in the sto-

machs of snoek caught on hand lines.

	FISH
Anchovy	<i>Engraulis capensis</i> Gilchrist
Blenny	Blenniidae spp.
Dogfish	<i>Poroderma africanum</i> (Gmelin)
Eel	<i>Leptocephalus</i> larvae
Garfish	<i>Scomberesox saurus</i> Fleming
Goby	Gobiidae spp.
Gurnard	<i>Trigla capensis</i> Cuvier
Hake	<i>Merluccius capensis</i> Castelnau
Kingklip	<i>Genypterus capensis</i> (Smith)
Lantern-fish	<i>Diaphus elucens</i> Brauer
	<i>Lampanyctodes hectoris</i> (Günther)
	<i>Myctophum humboldti</i> (Risso)
Lightfish	<i>Maurollicus muelleri</i> (Gmelin)
Maasbanker (horse mackerel)	<i>Trachurus trachurus</i> Linnaeus
Mackerel	<i>Scomber japonicus</i> Houttuyn
Pilchard	<i>Sardinops ocellata</i> (Pappe)
Round herring	<i>Etrumeus teres</i> (Dekay)
St Joseph	<i>Callorhynchus capensis</i> Dumeril
Sancord	<i>Gonorrhynchus gonorrhynchus</i> (Linnaeus)
Sandeel	<i>Ammodytes capensis</i> Barnard
Silverfish	<i>Argyrozona argyrozona</i> (Valenciennes)
Sole	<i>Austroglossus</i> spp.
Steentjie	<i>Spondyllosoma emarginatum</i> (Cuvier)
Vlei sardine	<i>Hepsetia breviceps</i> (Cuvier)

	CRUSTACEANS
Crabs	<i>Brachyura</i> spp.
Euphausiids	<i>Euphausia lucens</i> (Hansen)
	<i>Nyctiphanes capensis</i> (Hansen)
Mantis shrimp	<i>Squilla armata</i> Milne Edwards
Mysid	<i>Mysidopsis major</i> Tattersall
Rock lobster	Puerulus stages of <i>Jasus lalandii</i> (H. Milne Edwards)
	MOLLUSCS
Cuttlefish	<i>Sepia officinalis</i> Quoy & Gaimard
Squid	<i>Loligo reynaudi</i> (Orbigny)

The frequency of occurrence of the principal food items found in the stomachs of handline-caught snoek examined between 1958 and 1974 are listed in Table 1. Information was not available for 1964 and the results for 1968 and 1969 were combined because only a few stomachs were examined during those years.

Feeding takes place in the early morning and to a lesser extent in the evening. The snoek gorge themselves and then stop feeding till the stomachs are empty again. Because of this feeding habit, snoek fishing is mostly done during the early hours of the morning when the best catches can be made. This fixed feeding habit is probably one of the reasons for the high incidence (58 per cent) of empty stomachs found in the snoek caught on hand lines.

Snoek are voracious carnivores which feed mainly on fish, particularly pelagic fish, and to a lesser extent on molluscs and crustaceans. The occurrence of bottom-dwelling fishes such as soles, sancords and gurnards in some stomachs of handline-caught snoek suggests that feeding also occasionally takes place at the bottom.

Although snoek feed on a variety of animals, one species usually constitutes the principal food in a stomach. In only a few instances were snoek found to have fed on more than one species at a time. Shoaling snoek probably follow the shoals of fish on which they are preying. They usually feed on the species that is most available at a particular time. For example, from 1958 to 1963 when pilchards were particularly plentiful as reflected by the catches of purse-seiners, pilchards were the most consistently identified food component in the stomachs. From 1965, however, when anchovies were more readily available than pilchards, the number of stomachs containing anchovies exceeded that with pilchards. Similarly, in 1971, when mantis shrimps *Squilla armata* were present in large concentrations

from St Helena Bay to False Bay (Smithsonian Institution 1972), the number of stomachs containing this crustacean exceeded that containing other foods. In other years they were seldom found in the stomachs.

Although round herrings had first been recorded from pelagic catches in 1958, they were only identified as such in snoek stomachs from 1961. Some might have been present in earlier samples but recorded as pilchards because semi-digested round herrings can easily be mis-identified as pilchards.

The sizes of the fish in snoek stomachs ranged from small juveniles to large adults. The contents of 554 stomachs (47 per cent of the stomachs containing food) were weighed. According to these weights, the heaviest stomach content encountered consisted of five semi-digested pilchards with a total weight of 294 g. The largest individual prey item found was a maasbanker of 259 g. The largest pilchard and round herring recorded in the stomachs had weights of 132 g and 112 g respectively. Up to 30 juvenile anchovies (total weight 128 g) were noted in a stomach, and one stomach contained mantis shrimps to a total weight of 109 g.

Euphausiids were found in only a few stomachs (0,5 per cent) of snoek caught by hand lines and appear to be unimportant in the diet. This contrasts with the diet of the related species caught in Australia and New Zealand, where euphausiids were found to be one of the principal items of food (Blackburn 1957, Mehl 1969). The incidence of euphausiids in the stomachs of trawl-caught snoek, namely 13,4 per cent, was much higher than in handline-caught snoek. *Euphausia lucens* was found to be the dominant species.

The build of the snoek's jaw with powerful teeth and the virtual absence of gill rakers makes it unlikely that snoek will feed on sparsely scattered euphausiids. Therefore, for snoek to feed on euphausiids in quantity, as trawl-caught snoek were found to do, euphausiids must be densely concentrated. Concentrations of euphausiids could only occur near the bottom in day-time because their diurnal migrations take them to higher levels at night. All the trawled snoek were caught during the day.

As with handline-caught snoek, fish, in this case lantern-fish and to a lesser extent juvenile hake, were the most important component of the diet of trawled snoek, being present in 41 per cent of the stomachs or in 73 per cent of the stomachs containing food.

Table 1: Frequency of occurrence of main food items in headline-caught snoek stomachs

	1958		1959		1960		1961		1962		1963		1965		1966	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
<i>FISH</i>	183	74.7	48	57.1	32	41.0	33	10.7	6	7.7	54	36.7	44	60.3	83	44.1
Anchovy	2	0.8	-	-	9	11.5	-	-	2	2.6	3	2.0	31	42.5	20	10.6
Maabanker	15	6.1	7	8.3	-	-	3	1.0	-	-	3	2.0	5	6.8	8	4.3
Mackerel	1	0.4	4	4.8	-	-	1	0.3	-	-	-	-	-	-	53	28.2
Pilchard	161	65.7	32	38.1	20	25.6	15	4.9	4	5.1	34	23.1	4	5.5	2	1.1
Round herring	-	-	-	-	-	-	-	-	-	-	1	0.7	2	2.7	1	0.5
Fish remains	6	2.4	6	7.1	8	10.3	14	4.5	-	-	16	10.9	3	4.1	-	-
Other	2	0.8	-	-	1	1.3	2	0.6	-	-	-	-	1	1.4	-	-
<i>CRUSTACEANS</i>																
Euphausiids	1	0.4	-	-	1	1.3	-	-	-	-	-	-	-	-	-	-
Mantis shrimp	1	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Other	-	-	-	-	1	1.3	-	-	-	-	-	-	-	-	-	-
<i>MOLLUSCS</i>																
Cuttlefish	3	1.2	-	-	1	1.3	-	-	-	-	1	0.7	-	-	-	-
Squid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	1.2	-	-	1	1.3	-	-	-	-	1	0.7	-	-	-	-
Empty stomachs	59	24.1	36	42.9	46	59.0	276	89.3	72	92.3	91	61.9	29	39.7	105	55.9
Total stomachs	245	-	84	-	78	-	309	-	78	-	147	-	73	-	188	-

	1967		1968-1969		1970		1971		1972		1973		1974		All years	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
<i>FISH</i>	94	45.9	18	26.5	188	31.0	24	15.2	76	39.4	76	58.0	95	37.8	1 045	37.1
Anchovy	73	35.6	7	10.3	94	15.5	8	5.1	28	14.5	59	45.0	66	26.3	402	14.3
Maabanker	-	-	1	1.5	3	0.5	-	-	-	-	-	-	-	-	45	1.6
Mackerel	7	3.4	1	1.5	5	0.8	3	1.9	3	1.6	-	-	1	0.4	69	2.5
Pilchard	3	1.5	3	4.4	23	3.8	6	3.8	5	2.6	1	0.8	6	2.4	296	10.5
Round herring	9	4.4	-	-	53	8.7	5	3.2	28	14.5	7	5.3	14	5.6	50	1.8
Fish remains	9	4.4	2	2.9	19	3.1	2	1.3	14	7.3	11	8.4	9	3.6	171	6.1
Other	-	-	5	7.4	-	-	-	-	-	-	-	-	-	-	66	2.3
<i>CRUSTACEANS</i>																
Euphausiids	1	0.5	-	-	18	3.0	62	39.2	21	10.9	3	2.3	-	-	107	3.8
Mantis shrimp	1	0.5	-	-	7	1.2	-	-	2	1.0	2	1.5	-	-	12	0.4
Other	-	-	-	-	7	1.2	62	39.2	9	4.7	-	-	-	-	79	2.8
	-	-	-	-	4	0.7	-	-	10	5.2	1	0.8	-	-	16	0.6
<i>MOLLUSCS</i>																
Cuttlefish	-	-	1	1.5	29	4.8	3	1.9	8	4.1	9	6.9	6	2.4	61	2.2
Squid	-	-	-	-	13	2.1	2	1.3	1	0.5	2	1.5	2	0.8	20	0.7
	-	-	1	1.5	19	3.1	1	0.6	7	3.6	7	5.3	5	2.0	45	1.6
Empty stomachs	110	53.7	49	72.1	392	64.6	75	47.5	99	51.3	46	35.1	155	61.8	1 640	58.3
Total stomachs	205	-	68	-	607	-	158	-	193	-	131	-	251	-	2 815	-

ACKNOWLEDGEMENTS

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LENGTH-MASS RELATIONSHIPS, WATER CONTENT AND ENERGY VALUES FOR TWO SPECIES OF SQUID, *LOLIGO REYNAUDI* AND *TODAROPSIS EBLANAE*, OFF THE SOUTH-WESTERN CAPE

J. COOPER*

Length-mass relationships, the water content and energy values are given for two species of squid commonly caught in bottom trawls off the South-Western Cape. The data are of use in assessing the effect of predators on squid stocks.

Lengte-massaverwantskappe, die waterinhoud en energiewaardes word vir twee pylinkvisspesies wat algemeen in bodemsleepnette langs die kus van die Suidwestelike Kaap gevang word, verskaf. Die gegewens is bruikbaar by die bepaling van die invloed van predatore op pylinkvisstapels.

Squid (Cephalopoda) are commonly caught in bottom trawls on the continental shelf of South Africa (Sea Fisheries Branch 1976). At least one species, *Loligo reynaudi*, is of commercial importance. To date, nothing has been published on the length-mass relationships of South African squid, as has been for many other constituents (all fish) of the multi-species demersal fishery (Chalmers 1976).

Squid are important in the diet of many seabirds (Tickell 1964, Imber 1976), and it is most useful to relate the dimensions of squid beaks found in bird stomachs or in regurgitations to the original mass (weight) and energy content of the animal eaten (Maclean 1966).

This report gives the relationships between dorsal mantle length and body mass and lower rostral length and body mass, the water content and the energy values for two species of squid: *Loligo reynaudi* (Loliginidae) and *Todaropsis eblanae* (Ommastrephidae).

MATERIAL AND METHODS

Totals of 131 specimens of *L. reynaudi* and 88 specimens of *T. eblanae* were collected in March 1978 from 11 one-hour bottom trawls made by the R. S. *Africana II*, a Sea Fisheries Branch research vessel, during a research cruise directed at investigating hake recruitment. Trawls were made between Saldanha Bay and Cape Hangklip, i.e. around the south-western tip of South

Africa. Representative samples of squid from each trawl were deep-frozen and later defrosted in the laboratory. The squid were wiped dry of surface water, identified and weighed to an accuracy of 0.1 g up to 400 g and, above that, to an accuracy of 1 g. Dorsal mantle length was measured to the nearest 0.1 cm. The beaks were removed and the lower rostral length (Clarke 1962) was measured to the nearest 0.2 mm.

Several individuals of both species were dried to constant mass in a forced-draught oven set at 50°C in order to determine the percentage water content. The dried samples were analysed for energy value in a Phillipson microbomb calorimeter. The beaks and pens were not removed from these specimens.

RESULTS AND DISCUSSION

The length-mass relationships are shown in Figures 1 and 2 and water content and energy values for the two species of squid are given in Table I.

Squid were the sixth most valuable category landed in the South African multi-species demersal fishery in 1974 (Sea Fisheries Branch 1976). However, very little is known about the biology of squid in South African waters. Beak-mass relationships are of use in assessing the effect of predators on squid stocks (Maclean 1966) by showing what size, and therefore age-class, predators select – and in what quantities.

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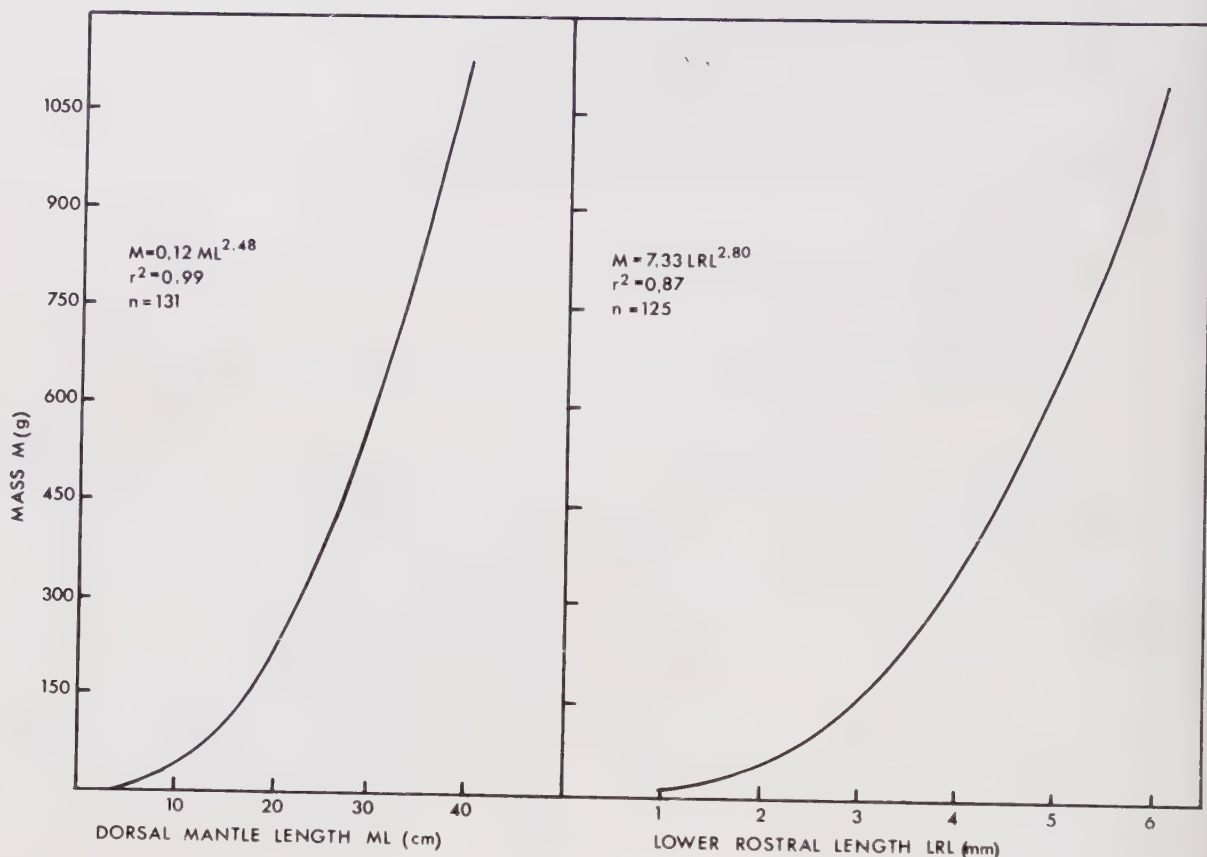


Fig. 1: Length-mass relationships of *Loligo reynaudi*

Table 1: Water content and energy values

Species	Number analysed	Water content* (%)	Energy value* (kJ/g dry mass)
<i>Loligo reynaudi</i>	9	76,3 ± 0,7 (74,4–77,0)	19,0 ± 0,6 (17,8–19,9)
<i>Todaropsis eblanae</i>	6	77,6 ± 2,0 (74,9–80,7)	19,9 ± 0,9 (19,2–21,5)

*All figures given are means ± standard deviation; the range is given in parenthesis.

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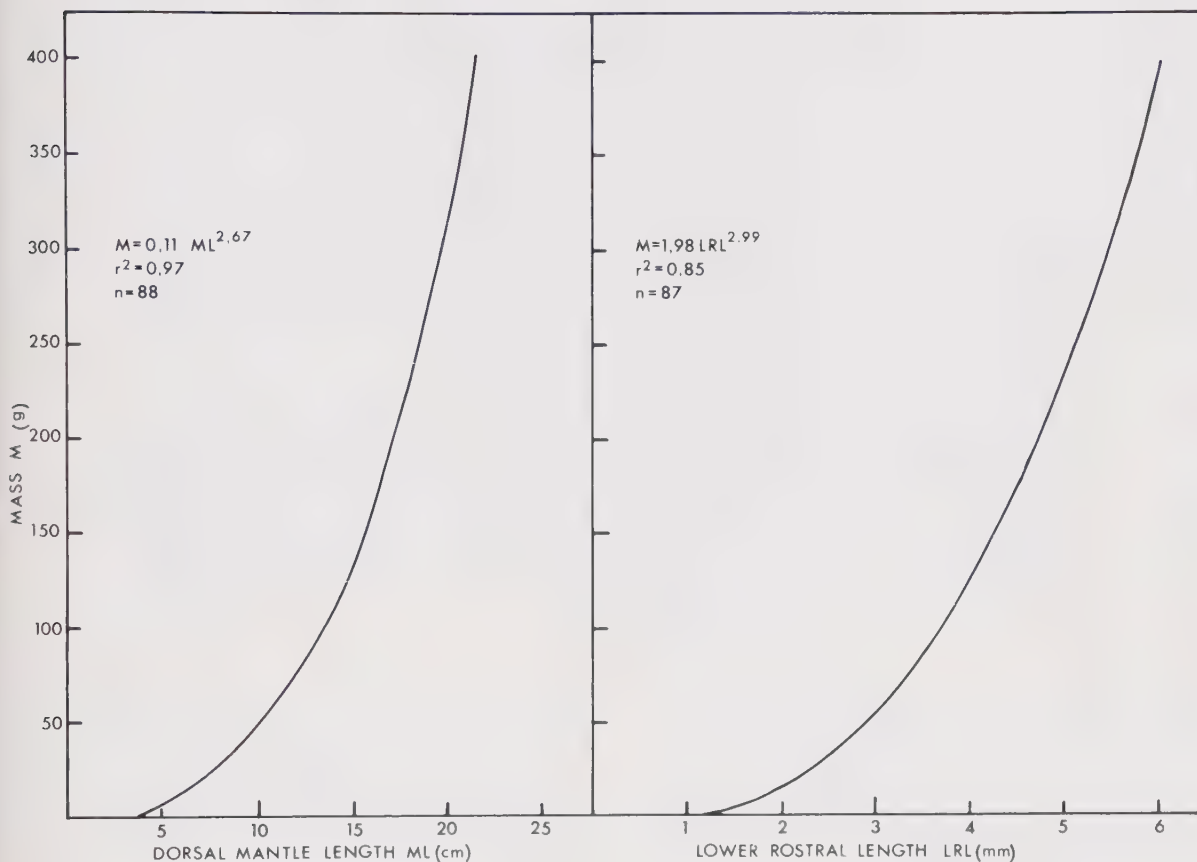


Fig. 2: Length-mass relationships of *Todaropsis eblanae*

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A RED-WATER OUTBREAK AND ASSOCIATED FISH MORTALITY AT GORDON'S BAY NEAR CAPE TOWN

P. C. BROWN, L. HUTCHINGS AND D. HORSTMAN

Red water at Gordon's Bay in August/September 1976 was caused by a dinoflagellate, *Gymnodinium* sp., and resulted in the mortality of a wide variety of fish. The extent of the bloom was established and a gross productivity value of $0,46 \text{ g C.m}^{-3} \cdot \text{hour}^{-1}$ estimated by changes in oxygen concentration in light and dark bottles. The net production was calculated as $0,405 \text{ g C.m}^{-3} \cdot \text{hour}^{-1}$. The bloom arose after calm, sunny conditions and was dispersed by south-easterly wind. A red-water extract did not cause death when injected intra-peritoneally into white mice. The high values of oxygen recorded led to the evaluation of its rôle as a cause of fish mortality. It is concluded that the most likely cause was clogging of the fish gills by high concentrations of the dinoflagellate.

Rooiwater te Gordonsbaai in Augustus/September 1976 is veroorsaak deur 'n dinoflagellaat *Gymnodinium* sp., en het tot gevolg gehad dat vrekte onder 'n wye verskeidenheid vissoorte voorgekom het. Die omvang van die opbloeïng is vasgestel en 'n brutoproduktieweïgswaarde van $0,46 \text{ g C.m}^{-3} \cdot \text{uur}^{-1}$ is beraam deur gebruik te maak van die veranderinge in suurstofinhoud in ligte en donker bottels. Die nettoproduksie is as $0,405 \text{ g C.m}^{-3} \cdot \text{uur}^{-1}$ bereken. Die uitbraak het ná kalm, sonnige toestande ontstaan en is deur 'n suid-oostelike wind verstrooi. 'n Ekstrak van die rooiwater het nie mortaliteit van witmuise veroorsaak nadat dit intraperitoneaal ingespuut is nie. Die hoë suurstofwaardes wat aangeteken is, het tot 'n evaluasie van suurstof se rol as 'n oorsaak van die visvrekte aanleiding gegee. Die slotsom was dat verstopping van die visse se kieuë deur die hoë konsentrasies van die dinoflagellaat die waarskynlikste oorsaak was.

Red water is a popular term describing unusually high concentrations of fresh-water or marine unicellular organisms which, by virtue of their pigments, cause a reddish discolouration of the water. Single dinoflagellate species normally bring about the red-water condition by sudden proliferation (bloom) in a relatively still body of water, usually during periods of high light intensity. Diatoms, flagellates and blue-green algae may individually be principal components (Grindley and Nel 1970). Although usually producing no visible effects on other organisms, red water has been known to presage animal mortalities, at times on a spectacular scale. However, certain toxic species of dinoflagellate, such as *Gonyaulax catenella*, which is well known off the Californian coast, sometimes have no direct adverse effects on the filter-feeding molluscs which ingest them and accumulate their toxin in the digestive gland, but indirectly cause paralytic shellfish poisoning in man (Grindley and Sapeika 1969).

Red water has been recorded regularly in the coastal waters of South Africa, particularly on the west coast. Outbreaks occur intermittently throughout the year, but more often in late summer, autumn and early spring (Horstman, unpublished data). The most common causative species in South African waters is the non-toxic dinoflagellate *Noctiluca miliaris*.

The history of shellfish poisoning in South Af-

rica has been documented by Grindley and Sapeika (1969). Gilchrist (1914) recorded several red-water outbreaks associated with fish mortalities. More recently, Grindley and Taylor (1964) reported a mass mortality of fish and invertebrates in False Bay in March/April 1962. The red water contained a very high concentration of the non-toxic dinoflagellate *Gonyaulax polygramma* and smaller numbers of another non-toxic dinoflagellate, *Prorocentrum micans*. The mortality in this case was probably due to depletion of oxygen by the decaying plankton. In December 1966, a high concentration of the dinoflagellate *Gonyaulax grindleyi* was associated with a mass mortality of many marine invertebrates on the west coast of South Africa (Grindley and Sapeika *op. cit.*). However, toxicity tests revealed that, although extracts of black and white mussels (including live specimens) were highly toxic to mice, extracts from the cells of *G. grindleyi* alone were not. Small numbers of a related species, *G. catenella*, were found in off-shore samples at the time. Grindley and Sapeika (*op. cit.*) suggest that the latter species, and not *G. grindleyi*, was the source of the toxin.

The present report deals with a dinoflagellate red-water bloom which appeared in Gordon's Bay (Fig. 1) at the end of August 1976 and persisted until the beginning of September. This bloom resulted in a mass mortality of fish, but not of invertebrates.

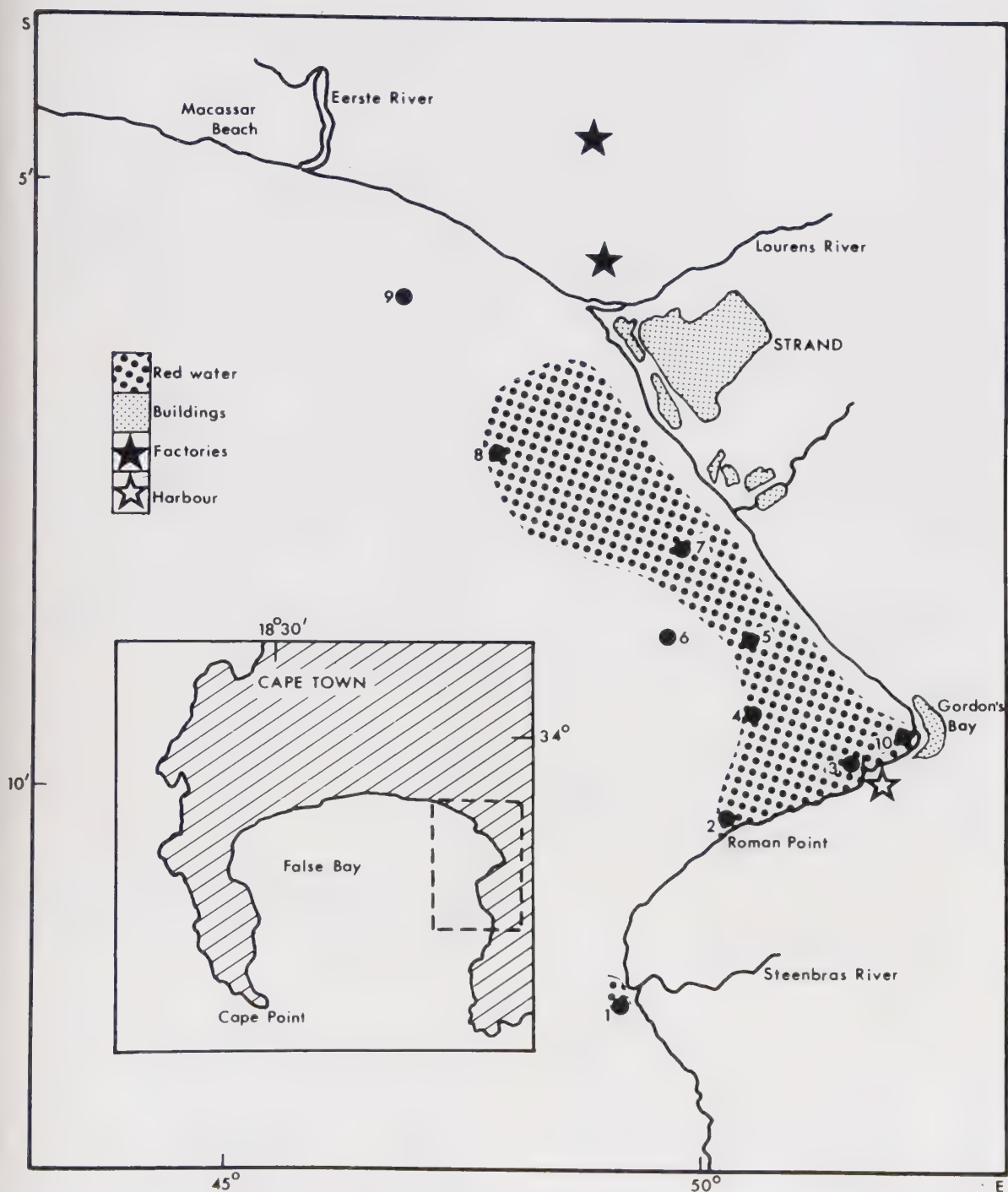


Fig. 1: Sampling stations and extent of discoloured water on 31 August 1976

On 28 August, discoloured water was reported at Gordon's Bay after a few days of calm, sunny weather. On the following day, it was partly dispersed off shore by a south-easterly wind. Patches of discoloured water were observed between Rooiels and Swartklip from a patrol boat on 30 August, but the main concentration centred in the area between Strand and Gordon's Bay. When the wind veered to the west, discoloured water was driven close inshore at Gordon's Bay and remained there for 48 hours. The sea was calm and the weather was sunny. The discoloured water was of a dark brown hue with no particular smell, and seemed to be limited, as is usual, to the surface, as was evinced by the normal colour of the water in the boat's wake. The bloom was completely dispersed on 2 September by a fresh south-easterly wind that had arisen late the day before.

METHODS

Survey

On the afternoon of 31 August a survey was made in the inshore waters along a zig-zag course from Rooiels to the mouth of the Lourens River, in order to establish the extent of the discoloured water (Fig. 1). At each of the 10 stations depicted in Figure 1, surface water samples were taken for dissolved-oxygen, salinity and phytoplankton analysis, the temperature was recorded and a bathythermograph cast was made. The soundings at the 10 stations ranged between 4 m and 16 m, but no subsurface water samples were taken because of lack of facilities. Sampling was terminated at nightfall.

Productivity

On 1 September, an attempt at assessing productivity within the bloom by means of the oxygen method was made. Four 250-ml pyrex reagent bottles (two "light" and two "dark") were filled with surface water obtained from a markedly discoloured area a few hundred metres outside the Gordon's Bay harbour. The water samples were then suspended about 0.5 m below the surface for four hours, from 13h25 to 17h25. At the time the incubation bottles were filled, water samples were also taken for estimation of oxygen and nutrient levels and for determination

of phytoplankton species and concentration. Ambient Secchi disc visibilities, surface temperatures and nutrient levels were recorded both immediately before and immediately after the incubation period.

Toxicity

While the incubation was proceeding, 50 l of discoloured water was collected and immediately taken to the laboratory, where an extract was prepared for toxicity tests according to the standard method of Prakash *et al.* (1971). The tests were carried out at the laboratories of the Department of Health, where the extract was injected intraperitoneally into white mice.

Effects on the fauna

Throughout the investigation, the shore was patrolled and any abnormalities were noted. The different species of fish washed up were recorded, and the gills of a few, including the white steenbras *Lithognathus lithognathus* were examined under a microscope. A small unaffected mullet was placed in a 5-l beaker of discoloured water, and its behaviour was observed.

The behaviour of the Southern black-backed gulls *Larus dominicanus* which were seen to eat the dead fish, was also noted.

RESULTS

Identification

The organism which caused the discoloured water was a small, naked dinoflagellate of the genus *Gymnodinium*, of a species which had not been recorded in this area before. Attempts at identifying the organism to species level failed.

No success was met in preserving the organism despite the use of a variety of fixing agents, e.g. formalin, alcohol, Lugol's solution and glyceraldehyde. Because the cells ruptured on addition of any of the fixing agents and because unpreserved specimens were too mobile, no cell counts were made. However, it was obvious that the cells were present in very high concentrations.

The organism could not be photographed with available equipment because it moved too rapid-

ly through the microscopic field and, when treated with MS 222, an anaesthetizing agent, it contracted into a spore-like sphere. For the same reasons, it was not possible to make accurate drawings. Microscopic examination under phase-contrast, however, established that a transverse sulcus and two flagella were present – one flagellum pulled the organism forward by its vigorous beating, while the second trailed passively behind. Because of the above-mentioned difficulties the species could not be established despite the use of the taxonomic works of Paulsen (1908), Lebour (1930) and Schiller (1937).

Survey

The surface water samples taken on 31 August revealed that the oxygen concentration (except that at station 1) throughout the surveyed area was very high (up to 11,77 ml O₂/l). The salinity ranged from 34,71‰ to 34,99‰ and temperatures varied between 14,6°C and 15,6°C (Table I). The bathythermograph traces showed very little variation (about 1–2 deg C) down the water column.

Table I: Surface oxygen, temperature, oxygen saturation and salinity

Station	Oxygen (ml/l)	Temperature (°C)	Oxygen saturation (%)	Salinity (‰)
1	—	14,9	—	—
2	8,51	15,4	147	34,83
3	11,77	15,6	204	34,76
4	7,92	14,9	136	34,84
5	8,51	15,2	147	34,83
6	7,52	14,7	128	34,88
7	7,66	14,9	131	34,99
8	7,43	14,6	127	34,85
9	6,87	14,9	118	34,73
10	3,79	15,6	66	34,71
Mean	8,27	15,1	142	34,82

Productivity

The ambient physical and chemical parameters measured at the incubation site on 1 September are given in Table II. The net production was calculated as 0,405 g C.m⁻³.hour⁻¹ taking into account the estimated gross productivity value of 0,46 g C.m⁻³.hour⁻¹ and respiration of 0,066 g C.m⁻³.hour⁻¹. However, the net production over one day (24 hours with 11,3 hours day-

Table II: Ambient physical and chemical parameters measured at the incubation site

Parameter	Discoloured water (before the incubation)	Green water (after the incubation)
Oxygen (ml/l)	8,31	Not done
Temperature (°C)	15,50	14,20
Secchi disc (m)	1,20	2,10
Calculated 1-per-cent-light depth (m)	1,30	2,60
Nutrients (µg-atom/l):		
Nitrate	2,78	1,61
Silicate	19,10	16,20
Reactive phosphate	2,76	1,35

light) was calculated to be 3,743 g C.m⁻³.day⁻¹ or 0,156 g C.m⁻³.hour⁻¹ (Table III).

During the incubation period, a south-easterly wind arose and the surface temperature dropped from 15,5°C to 14,2°C. Tongues of greenish water penetrated the red water, displacing it off shore. The 1-per-cent-light depth at the incubation site, as calculated from Secchi disc measurements (Poole and Atkins 1929), deepened from 1,3 m to 2,6 m. Nitrate values were very low both in the discoloured water and in the green water, while silicate and reactive phosphate concentrations were high (Table II). All nutrient concentrations were slightly higher in the discoloured water than in the green water.

Table III: Respiration and gross and net production

Respiration	0,12 ml O ₂ .l ⁻¹ .hour ⁻¹ 0,066 g C.m ⁻³ .hour ⁻¹
Gross production during daylight	0,460 g C.m ⁻³ .hour ⁻¹
Net production during daylight	0,405 g C.m ⁻³ .hour ⁻¹
Net production (over 24 hours including 11,3 hours of daylight)	0,156 g C.m ⁻³ .hour ⁻¹ 3,743 g C.m ⁻³ .day ⁻¹

Toxicity

The intraperitoneal injections of the phytoplankton extract caused acute morbidity, but not death, in the white mice. However, the background information about the sample itself was insufficient to conclude that the phytoplankton was the sole cause of the abnormal behaviour in the mice.

Effects on the fauna

From 30 August to 1 September, numerous fish were washed up into the shallows and on to the beaches near Gordon's Bay. Some were dead but many were still alive. The local people flocked to the beaches to collect bags of fish, despite being warned of the dangers of eating them. The following species were identified according to Smith (1965), some scientific names being updated according to more recent literature:

White steenbras	<i>Lithognathus lithognathus</i> (Cuvier)
Kob	<i>Johnius hololepidotus</i> (Lacépède)
Cape silverside	<i>Hepsetia breviceps</i> (Cuvier)
Southern mullet	<i>Mugil richardsonii</i> (Smith)
Strepie	<i>Sarpa salpa</i> (Linnaeus)
Geelbek	<i>Atractoscion aequidens</i> (Cuvier)
Leervis	<i>Hypacanthus amia</i> (Linnaeus)
Elf	<i>Pomatomus saltator</i> (Linnaeus)
Tasselfish	<i>Sciaena capensis</i> (Pappe)
Zebra	<i>Diplodus trifasciatus</i> (Rafinesque)
Blacktail	<i>Diplodus sargus</i> Linnaeus
Various sharks	

The first three species were the most abundant.

The small mullet which had been placed in a beaker of discoloured water showed signs of stress after a few hours, and by the following morning was dead. When examined under a microscope, its gills appeared to be clogged with the dinoflagellate. The same was noted with the gills of the fish picked up on the beach. Though not by any means a stringent test, it is suggested that gill clogging may have caused the mortalities.

Although many Southern black-backed gulls were seen to eat the dead fish, no abnormal behaviour or death of these birds was observed. In humans, no ill effects were reported from consuming washed-up fish.

DISCUSSION

Productivity

In view of the supersaturated oxygen levels encountered, the results of the productivity experiment must be treated with caution because the

oxygen method becomes less sensitive when applied to very high or very low oxygen levels. It would follow that production values would, in this case, be underestimated rather than overestimated.

Except for those recorded off South West Africa, the primary productivity values in this dinoflagellate bloom are higher than any given by Strickland (1966) in his Table IX, which gives selected measurements of marine phytoplankton productivity from different areas. Ragotzkie and Pomeroy (1957) used the oxygen method to measure net production values in a *Gymnodinium* bloom and gave values of 2,18 – 13,9 g C.m⁻³. day⁻¹. Our value of 3,743 g C.m⁻³. day⁻¹ (Table III), although it falls within the above range, is probably an underestimate of the actual net production for the reason given earlier.

It is interesting to note that the bloom was still growing vigorously just prior to being dispersed, although nitrate levels were very low both in the discoloured water and in the cooler green water. The low nitrate level and higher silicate level suggest that relatively more nitrogen than silica was bound up in the phytoplankton. This finding contrasts markedly with the normal diatom-dominated west coast situation where low nitrates are associated with low silica levels (Sea Fisheries Branch, unpublished data).

Dinoflagellates normally bloom close to the surface in calm, sunny conditions (Prakash 1975), whereas diatoms predominate during more turbulent conditions. Very often the highest concentrations of diatoms are found below the surface at sub-maximal light levels. In areas of intense upwelling, such as are found on the west coast of southern Africa, diatoms are generally the most important autotrophs.

On this particular occasion, upwelling caused the discoloured surface water to be transported off shore. Horizontal mixing of the upwelled and discoloured water took place, causing dilution of the bloom. In addition, the strong south-easterly wind caused increased vertical mixing in the upper layers, further diluting the discoloured water. Presumably the rate of dispersion exceeded the growth rate of the dinoflagellates, and the bloom disappeared.

Moreover, the growth rate of dinoflagellates under dispersing conditions (wind and/or upwelling) may not be the same as under calm conditions. The increased vertical mixing would force the dinoflagellates to lower light levels, thereby lowering their growth rate. White (1976) found that shaking of cultures of the toxic red-water dinoflagellate *Gonyaulax excavata* resulted in a

definite decrease in growth rate. Therefore, the disappearance of the discoloured water was probably caused by a combination of the physical dilution of the bloom and a decrease in growth rate.

In addition, the maintenance of the bloom in the upper layers during calm conditions poses considerable problems regarding the recycling of nutrients, especially nitrate. The highly mobile organisms may periodically migrate to deeper levels to replenish their nutrients or the nitrates may be recycled rapidly in the upper layers. The nature of the sampling during this survey unfortunately precluded any detailed investigation of these issues.

Mortality

The reason for the mortality of fish, though clearly linked with the outbreak of discoloured water, is not definitely known but several possibilities can be put forward:

Gill clogging – This seemed to be the most likely cause for the following reasons: Firstly, when examined under a microscope, the gills of the fish were thickly coated with the organism. Secondly, specimens of almost all the different species of fish normally found in the area (irrespective of whether they are filter feeders or not) were washed up on the beaches.

It is interesting to note that neither galjoen *Coracinus capensis* nor any flatfish species were reported to have been washed up, although they are known to be common in the area. Because they are adapted to living on sandy or muddy bottoms, flatfish may be able to deal with fine sediment or, in this case, dinoflagellates. However, the absence of galjoen amongst the washed-up fish is difficult to explain, particularly as the discoloured water extended through the surf zone (their normal habitat) and into the rock pools.

Hypoxia – Oxygen deficiency at night may have caused the red-water mortality. The very high levels of dissolved oxygen recorded in the water during the day may have been absent at night when photosynthesis stopped and respiration continued. The oxygen concentration could drop below a critical level and result in an oxygen gradient too small to allow sufficient oxygen to diffuse across the gill membranes to sustain the fish. Unfortunately, no oxygen measurements were made at night, so this argument is

purely hypothetical.

It was reported by the Sea Fisheries inspectors that more fish were found washed up during the early morning low tide than during the midday low tide. If this were the case, then perhaps the renewed photosynthesis during the day and the resulting increase in oxygen allowed some fish to recover. It could be argued that there would be fewer people picking up fish (thereby clearing the beach) during the night than during the day, and that this would make it seem as though more fish were being washed up at night. However, people did collect fish by torch-light during the early hours of the morning, and not as many people as would have been expected were able to go down to the beach during the day because most were at work.

Red water in the Los Angeles area has been responsible for fish mortalities (Oguri *et al.* 1975). As the bloom became senescent and oxygen levels fell, fish appeared at the surface, gasping, as though for oxygen. When transferred to well oxygenated aquaria, the fish recovered. In Gordon's Bay, however, the bloom was still growing vigorously, and could hardly be regarded as senescent. Oxygen values, recorded only during the day, were all at supersaturated levels.

If the rate of respiration through the night is assumed to be 0.12 mO₂/l/hour (measured during the incubation), then, by extrapolation, the oxygen level of 8.31 ml O₂/l (measured at the beginning of the incubation) would drop, after 12 hours of no photosynthesis, by 1.44 ml to 6.87 ml O₂/l. At 15°C and 35.23‰ salinity, the latter value represents 114-per-cent saturation. Therefore, it does not seem likely that hypoxia could have been the cause of the fish mortality.

Hyperoxia – The very high level of oxygen recorded on both sampling days (Tables I and II) indicates that hyperoxia might have been the cause of the mortality by saturating both the blood and the haemoglobin with oxygen, thereby preventing carbon dioxide from being off-loaded into the blood and disposed of. However, because little is known about the physiology of respiration of the local fish, no further comment on the influence of this factor can be made.

Oxygen embolism – The very high oxygen levels show the surface water to be grossly supersaturated (Table I). Nebeker *et al.* (1976) found that when salmon *Oncorhynchus nerka* were exposed to air-supersaturated water, the lethal threshold was 114-per-cent saturation. At 120-

per-cent saturation, the first mortality occurred after 77 hours, and after 127 hours, 40 per cent of the test fish were dead.

The fact that levels of this order were found at Gordon's Bay suggests that the mortality could have been caused by gas embolism in the fish induced by supersaturated water resulting from very high production in the dinoflagellate bloom. Living in the surf zone, galjoen may be adapted to excess aeration and would not have been affected by the oxygen bubbles. This could explain their absence amongst the moribund fish.

Toxicity – Toxicity studies showed that, although the phytoplankton extract had some effect on white mice, it was not lethal. Seagulls that had eaten the fish were not affected, indicating that the fish mortality was not caused by anything toxic to both fish and birds. However, a toxin could quite possibly have very different effects on species as varied as white mice, birds and fish. Future tests should preferably use fish, as well as white mice, as test animals.

CONCLUSIONS

The dinoflagellate bloom causing the red-water condition occurred in high concentrations at the sea surface even though the organism may have been present further down the water column. It was dispersed by increased turbulence at the surface and off-shore transport of upwelled water caused by a south-easterly wind. The high productivity values measured in the red water just before dispersion indicated that the bloom was still growing vigorously, and that the disappearance of the red water was not due to lack of nutrients or some natural physiological tailing-off of growth, but rather to the physical effects mentioned above.

The most likely cause of the fish mortality was clogging of the gills by high concentrations of the dinoflagellate.

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